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TECHNIQUES AND PROCEDURES APPLIED TO PHOTOMETRIC METHODS FOR THE ANALYSIS OF HUMAN KINEMATIC RESPONSES TO IMPACT ENVIRONMENTS

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OCTOBER 1980

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TECHNICAL REVIEW AND APPROVAL

AFAMRL-TR-80-61

The experiments reported herein were conducted according to the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

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Director
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This report presents the methods, techniques, and procedures developed and applied to photometrically evaluate the biodynamic responses of body segments to laboratory simulations of aircraft crash and escape system environments. These simulations were developed on the Horizontal Impulse Accelerator, the Hydraulic Decelerator, and the Body Positioning Retraction Device, all of which are facilities of the Biomechanical Protection Branch of the

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Block 20. Abstract (Continued)

Air Force Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, by personnel of that organization.

Application of these methods and techniques resulted in time histories of coordinate positions, relative to the test seat, of anthropometric points during the impact and response periods.

The coordinate system defined for each of the experimental test programs is described. Coordinate positions of reference points and camera locations in the various coordinate systems are documented. The techniques used to locate and mark anthropometric points on the test subjects are described.

The tracks of the marked anthropometric points were recorded throughout each test event on 16 mm motion picture cameras operating at a nominal speed of 500 frames per second. Projected image coordinates of the tracked points were digitized semi-automatically from each of the frames during the event and were electronically processed to time-seat coordinate position histories for displacement, velocity, and acceleration analysis.

A

SUMMARY

The methods, techniques, and procedures employed to describe, from high speed motion picture records, the motions of body segments resulting from sudden application of external forces to specific areas of the body are outlined herein.

Processes were applied to two basic types of motions, planar and nonplanar. Planar motion generally resulted from two types of head on crash simulations, rearward acceleration of the test vehicle from a standing position by the Horizontal Impulse Accelerator, and deceleration of the test vehicle from forward motion by the Hydraulic Decelerator, and from the upper torso retraction environment simulated on the Body Positioning Retraction Device. Nonplanar motion resulted from head on crash simulations [illegible] which the subjects were asymmetrically restrained, and from [illegible] on crash simulations.

Prior to each experimental test program the photometric data requirements were specified. These specifications determined the number of cameras to be used and their locations and orientations. The specifications also determined the number of moving points to be tracked and identified them. Reference points in the field of view of each camera were [illegible] cials and their coordinates were measured [illegible].

The recorded test data were projected, [illegible], a viewing screen equipped with horizontal and vertical [illegible] the relative positions of which were digitally encoded by [illegible] shaft angle encoders attached to the shafts of the [illegible] knobs. The encoders excited up-down counters which [illegible] horizontal and vertical displacement from the center [illegible] jected image of each of the points read. [illegible] then computer processed to time histories of two [illegible] sional coordinate positions and time histories [illegible] acceleration were derived.

The techniques and procedures applied to reduce data from each of the major test programs are described in this report.

The coordinate solutions were adequate to use as comparisons with predicted trajectories of the various points. With the exception of the Injury Protection Comparison study and the elbow trajectory data from the $-G_x$ (6, 8, and 10G) study, errors in solution were less than one-eighth inch. Large errors in x-component of displacement were evident in the data from the Whole Body Restraint-Lateral test program. The indications are that the angle between the optical axes of the cameras (11 and 12) was too small.

Derived velocity and acceleration data are not sufficiently accurate to use for predictions. Improved filtering methods and greater accuracy in coordinate solutions would be required to improve the utility value of these data.

PREFACE

The work described herein was accomplished for the benefit of the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio under Contract F33615-76-C-0525 during the period 1 September 1976 through 30 April 1979. This contract was monitored initially by Major John P. Kilian and later by CMSgt. Joseph M. Powers of the Biomechanical Protection Branch, Air Force Aerospace Medical Research Laboratory.

University of Dayton personnel who made major contributions to the program include William J. Hovey, Project Supervisor, Henry T. Mohlman and Ronald C. Reboulet, Research Mathematicians, and Philip A. Graf, Research Technician.

The authors gratefully acknowledge the cooperation and assistance provided by Mr. Jim Brinkley, Branch Chief, Maj. John Kilian and CMSgt. Joseph Powers, the Contract Monitors, the Project Engineers and Principal Investigators and all other personnel of the branch. Assistance and cooperation of personnel of the Technical Photographic Division, 4950th Test Wing, and of the Digital Computer Operations Division, Aeronautical Systems Division, are also gratefully acknowledged.

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SECTION 1
INTRODUCTION

The high injury and fatality rates associated with vehicular crashes and emergency escape from aircraft dictate the need for determination of impact exposure limits and the evaluation of the effectiveness of various protection system configurations and protection principles and techniques. In response to these needs, the Biomechanical Protection Branch of the Air Force Aerospace Medical Research Laboratory (AMRL/BBP) has rigorously conducted experimental test programs, developing in the laboratory simulations of the environments to which crewmen might be exposed. Data collected from these experimental programs provide the bases for verification and/or improvement of predictive biodynamic models.

This report describes and documents the photometric analysis procedures and processes developed and applied by the University of Dayton Research Institute (UDRI) during the period 1 September 1976 thru 30 April 1979, in support of AMRL/BBP research and development programs.

The photometric work accomplished is summarized as follows:

- DOT 6 Year Old Child Comparison. The reduction of photometric recordings of points on the heads of dummies and baboons to time histories of three dimensional coordinate positions was completed.
- Restraint System Dynamics. Preparation of test subjects by application and documentation of tracking fiducials was accomplished. Reduction of film data to two dimensional time histories of displacement, velocity, and acceleration of six points on the heads and extremities of nine human subjects and one manikin during ninety-one tests was completed.
- Whole Body Restraint-Lateral. Preparation of subjects by application and documentation of tracking fiducials was accomplished prior to each test. Reduction of film data

to time histories of three dimensional displacements, velocities, and accelerations of nine points on the heads and torsos of ten human subjects and three manikins acquired during fifty three of the tests was completed.

- Upper Torso Retraction. Preparation of subjects by application of fiducials and measurement of variable breadths was accomplished prior to each test. Film data collected during two tests were reduced to two dimensional time histories of displacements, velocities, and accelerations of nine points on the subject and one point on the retraction piston.

- Impact Protection Comparison, $-50\ G_x$ Accelerator. Preparation of subjects by application and documentation of fiducials was accomplished prior to each of eighteen tests. Data were digitized from seventeen of the tests and were reduced to time histories of displacements, velocities, and accelerations of six points on each of the subjects.

- Impact Protection Comparison, $-50\ G_x$ Decelerator. Preparation of subjects by application and documentation of fiducials was accomplished prior to each of twelve tests. Film data from eleven tests were digitized and reduced to time histories of displacements, velocities, and accelerations of six points on each of the subjects.

- F-111 Generic Study, $-G_x$. Preparation of subjects by application of fiducials and measurement of their relative locations was accomplished prior to each test. A process was developed to plot pictograms of the head and extremities of the subject and the projection of the harness geometry in the X-Z plane. The process was demonstrated with data digitized from film(s) of test(s).

The results of the photometric data reduction [illegible] were reported in tabular and graphic forms. The procedures and pro- cesses employed to derive the reported results were [illegible] narrative texts to which the results were [illegible]. [illegible] sections describe, in greater detail, those procedures and pro- cesses, to facilitate application [illegible] future [illegible] problems.

SECTION 2

ANALYSIS OF PLANAR MOTION

Exposure of symmetrically restrained [illegible] $\pm G_z$ acceleration environments usually result [illegible] points on these subjects. While [illegible] the extremities is demonstrated, it is not [illegible] tude as to warrant three dimensional analysis. [illegible] point, or points, were described by data [illegible] recorded on a single motion picture camera and [illegible] by the Horizontal Impact Facility Photometric Data Analysis Program (HIFPD). The test programs from which data were reduced using this process were:

- Restraint System Dynamics
- Upper Torso Retraction
- Impact Protection Comparisons, -50 [illegible]

The original version of HIFPD was developed during an earlier effort and was documented in AMRL-TR-78-94. The process has since been modified by the addition of three subroutines, rotate, mean 1, and mean 2, which were developed to improve accuracy by minimizing the effects of camera vibration and pin registration variations, and to provide statistical indications of reading accuracy and smoothing effects. The current version of this program is described in the following sections and listing of the program source statements is presented in Appendix A.

2.1 THEORY

When a camera photographs a scene, the film receives an image of an infinite number of rays of light emanating from an infinite number of points in the scene. If the lens through which the rays pass is such that it introduces no distortion, then the image of a given observed point will strike the film at a distance, r_1, from the center of the image of the entire scene in direct relationship to the distance, r_o, from the optical axis [illegible] the observed point in the plane normal to the optical axis, at a [illegible] tance, s_o, from the focal point in which the [illegible]

Figure 1 illustrates this relationship.

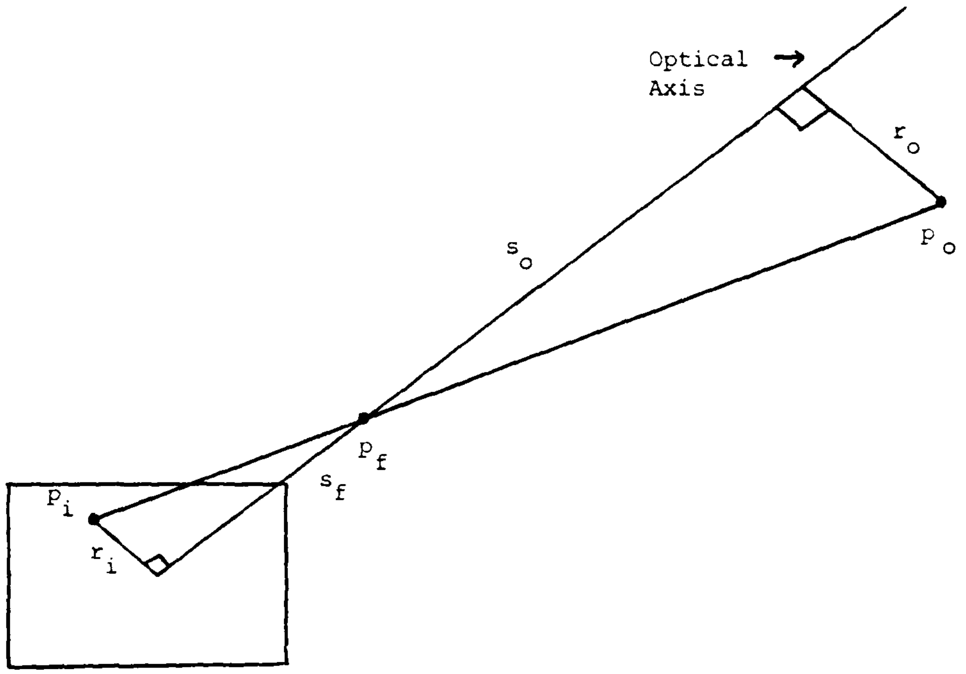


Figure 1. Observed Point and its Film Plane Image Relative to the Optical Axis.

Having the focal length of the lens, s_f, given by the manufacturer and the measured distance, r_i, the distance, r_o, can be calculated by similar triangles to be:

$$r_o = s_o\left(\frac{r_i}{s_f}\right).$$

This does not, however, permit the determination of the vector direction of r_o from the point at which the optical axis penetrates the object plane.

If one could construct a perpendicular set of axes, x and z, in the object plane, for instance a horizontal and a vertical line, intersecting at the optical axis, then the vector direction of the line segment, r_o, can be determined by measuring the angular displacement of its image, r_i, from the image of the x axis or by measuring the coordinates of the image point, p_i, and solving for

the angle:

$$\theta_i = \tan^{-1} \frac{Y_i}{X_i}.$$

as in Figure 2. Construction of material axes in the observed scene is usually not practical so an alternate method will be offered later in the discussion.

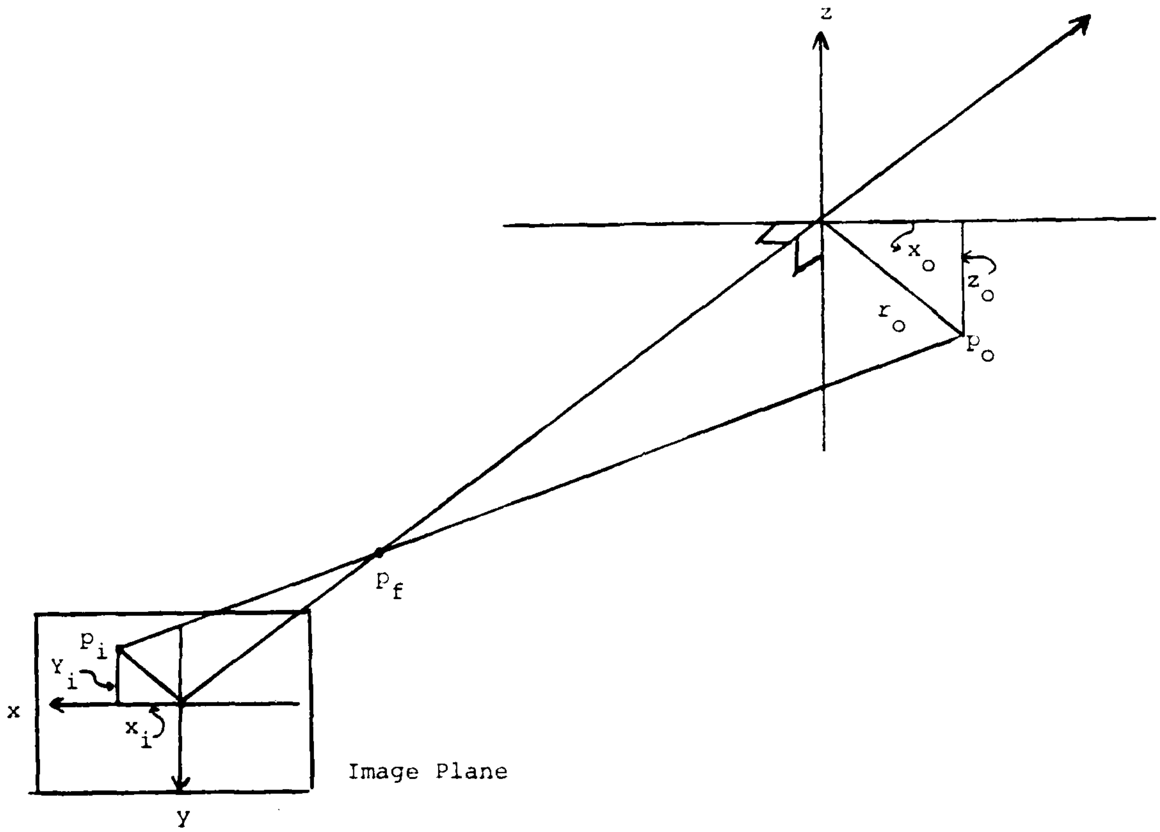


Figure 2. Film Plane Image of Scene Coordinate Axes.

Since the image recorded on the film is so small, it is impractical, if not impossible, to determine the coordinates of the image point without magnification. The required magnification is usually provided by a projector, although microscopes have also been used. If a projector is used, and its lens introduces no distortion, then the screen, or projected image plane, could be

considered the equivalent of a plane, normal to the optical axis, that existed between the focal point of the camera and the scene viewed by the camera at a distance, s_p, from the focal point (Figure 3). Now, again assuming no distortion, we have the relationship:

$$\frac{r_i}{s_f} = \frac{r_p}{s_p} = \frac{r_o}{s_o} .$$

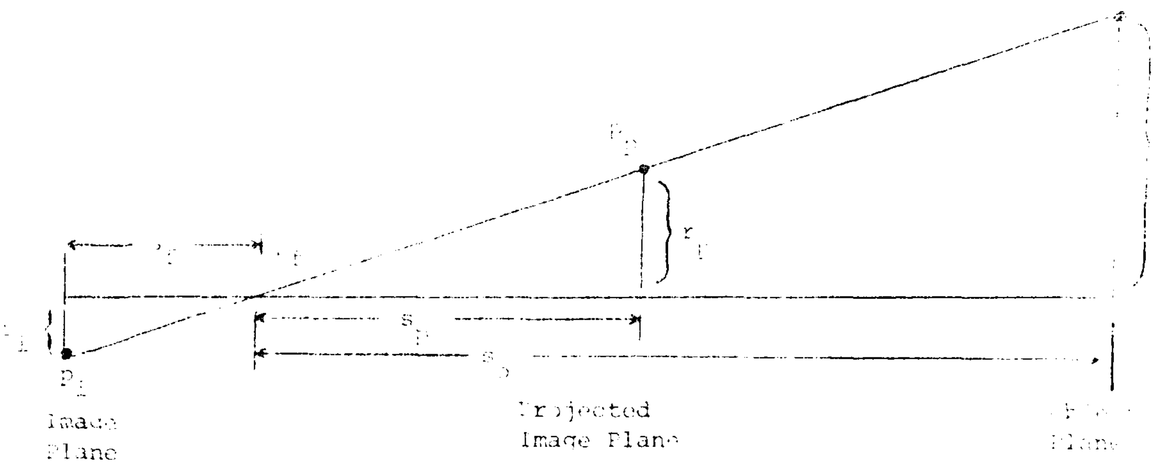


Figure 3. Relationship Existing Among Image Plane, Projected Image Plane and Object Plane.

If a second point, p_{o2}, on a line parallel to the optical axis and passing through the first object point (such that $r_{o2}=r_o$) is observed, the distance, r_{p2}, from the optical axis (or center of projected image) to the projected image point, p_{p2}, is related to the distance s_{o2} as the distance r_{o2} is related to s_{o2}, i.e.:

$$\frac{r_{p2}}{s_p} = \frac{r_{o2}}{s_{o2}}$$

This is illustrated in Figure 4.

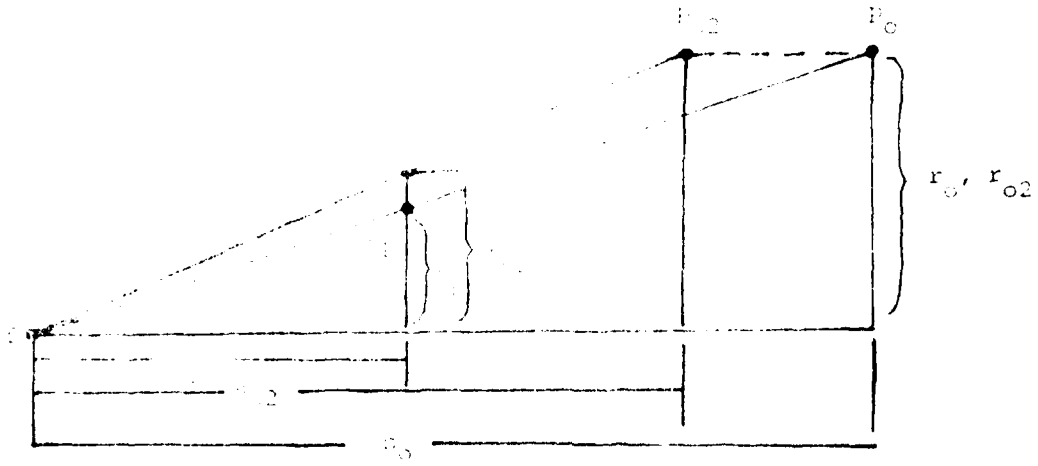


Figure 4. Projected Images of Observed Points Equidistant from Optical Axis but Lying in Different Planes Normal to the Optical Axis.

Now let us return to the problem of relating the orientation of the film frame image to the observed scene. As has been stated, it is usually not practical to draw a set of axes on the observed scene. It is, however, practical to establish a coordinate system in the scene and survey the coordinates of several fixed points of reference in the established system. Figure 5 illustrates the projected image of the points p_o, the origin of the scene coordinate system (SCS) and p_1 and p_2 which are surveyed reference points. For the sake of simplification, the three points are coplanar in a plane, y=n, normal to the optical axis although in practice this is not required. The images of these points are projected on a viewing screen on which a coordinate system is imposed, which we shall call the projected image coordinate system (PCS). Having the coordinates in the SCS of the two observed points P_{o1} and p_{o2}, the projected image can now be rotated relative to the PCS to satisfy the relationship:

$$\frac{y_{P_{p1}} - y_{P_{p2}}}{x_{P_{p1}} - x_{P_{p2}}} = \frac{z_{po1} - z_{po2}}{x_{po1} - x_{po2}}$$

this can be accomplished physically by rotating the axes of the digitizer. If the digitizer is not equipped with rotating axes, or with rotating film transport, the rotation can be accomplished mathematically by:

$$x' = x \cos \theta + y \sin \theta$$
$$y' = y \cos \theta - x \sin \theta$$

where θ is the angular displacement of the SCS from the ICS about the optical axis.

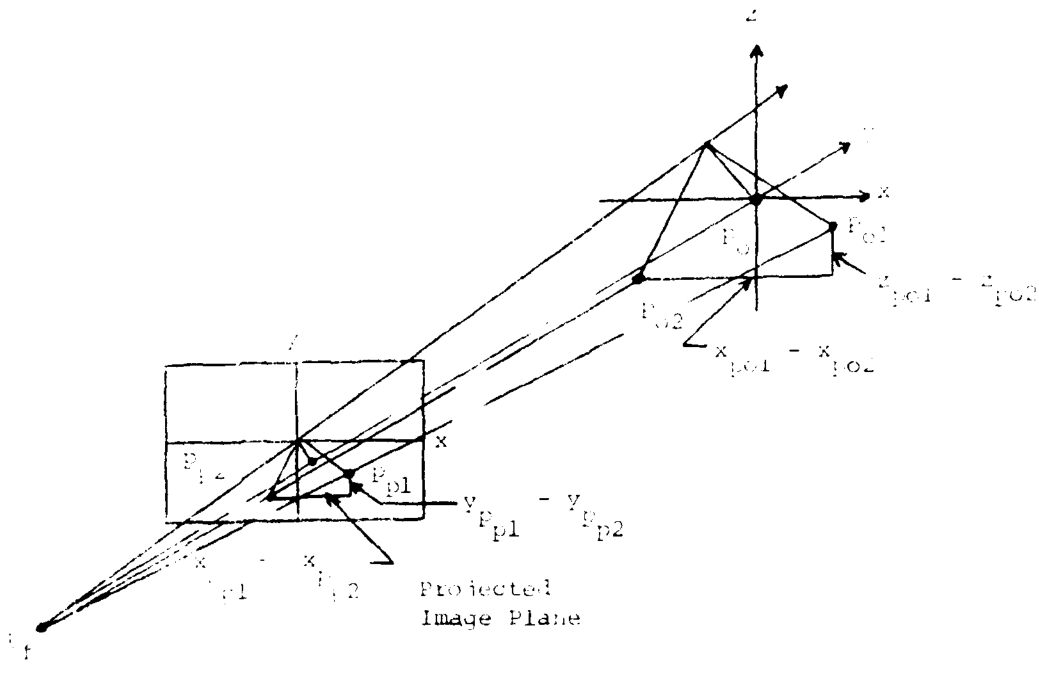


Figure [illegible]. Relationship between Projected Image Coordinate System and Scene Coordinate System.

2.2 HORIZONTAL IMPACT FACILITY PHOTOMETRIC DATA ANALYSIS PROGRAM (HIFPD)

Horizontal Impact Facility Photometric Data Analysis Program (HIFPD) is a digital computer program [illegible] the Hyge Impact Facility Photometric data for [illegible] Protection Branch of the Biodynamics Bioengineering Division [illegible] AFAMRL. The program was compiled and executed on the CDC computers at Wright-Patterson Air Force Base. The [illegible] plot package is used to plot data and thus must be [illegible] to load and execute the program.

This program inputs the code sheet data and program control prarameters described in the section entitled "Description of Program HIFPD Input Data and Parameter Codes" and a maximum of [illegible] (MAXN) frames of x, z position data for the range, sled, hip, knee, shoulder, elbow, head point 1 and head point 2 for ITYPE=0 or range, sled, head point 1 and head point 2 for ITYPE=1. The data card format are also described.

The program computes the following four types of data as requested by the program control parameters:

(a) The input data versus frame number and the frame to frame differences are printed in counts. The range difference is subtracted from the frame to frame differences for each of the seven parameters. The only value of this difference data would be to spot errors in the data. When the input data are rotated and translated (ICAM=1), the resulting adjusted data are also printed versus frame number (still in counts).

(b) The displacements (x and z) of the hip, knee, shoulder, elbow, head point 1 and head point 2 relative to the sled [illegible] computed, and a moving eleven point (NP 11) quadratic least square fit is used to smooth the data. These data are also plotted, if requested on the test setup card.

(c) The angles in radians between the shoulder and hip and between the head point 1 and head point 2 are computed using the above smoothed data. The angular velocity is computed in

radians per second using a moving 11 point quadratic fit of the angle versus time data (computes derivative of least square equation). The angular acceleration is computed using a moving eleven point quadratic fit of the velocity versus time data. These data are also plotted as requested on the test setup card.

(d) The linear velocity and acceleration data for any combination of the eight variables are computed as requested on the test setup card. For example, the linear velocity and acceleration of the head point 1 relative to the range, sled relative to the range or the head point 1 relative to the sled can all be computed. Note that range relative to some other parameter cannot be computed. To compute these linear velocity and acceleration data, the x and z displacements are computed for the variable of interest relative to the reference variable. A moving eleven point (NP=11) quadratic least square smoothing function is applied to both the x and z time histories. A moving eleven point quadratic least square fit is then applied to these smoothed x and z-axis displacement data to obtain the x and z components of velocity. Next this same smoothing routine is applied to these x and z-axis velocity data to compute the x and z components of acceleration. The resultant displacement, velocity, and acceleration data are then computed using these smoothed x and z component data. These data are printed and plotted as requested on the test setup card.

The three external files used by this program are the input file (unit 5) used to read all code sheet and data cards. The output file (unit 6) used to print all output, and TAPE7 (unit 7) used to generate the plotter tape. A magnetic tape must be requested with TAPE7 as the local file name.

The following sections of this report present a general description of the main program and all subroutines except the CAL COMP plot routines. Flow char's are also included for each routine. Appendix C contains a complete listing of the program source deck and Appendix D contains a sample run complete with all input and output data (including CALCOMP plots).

[illegible] Main Routine

This main routine controls all input, output and [illegible] [illegible] requested by the test [illegible] [illegible] routines required to smooth the data, [illegible] results are cal[illegible] [illegible] resulting from errors in setup or data card [illegible] [illegible] this routine.

Method

The program reads the code sheet [illegible] described in the "Description of Program [illegible] Input and [illegible] Codes" section and initializes the program [illegible] parameters. The program reads the [illegible] and z axis data for [illegible] for each frame [illegible] card code are checked for input errors: errors in input cause diagnostics to be printed and the processing to be terminated. If more than MAXN frames are read, diagnostics are printed and all frames beyond MAXN are omitted from the analysis. The T(I) time [illegible] are computed from the frame number as follows:

T(I)=IFR(I)/DT

where IFR(I) is the frame number and DT is the number of frames per second. If setup card parameter IRX is greater than zero, the sign of all x axis data are changed. Also when code sheet parameter IADJ is greater than zero, adjustment factors XADJ and ZADJ are added to all x and z axis data. After all data are read, a summary page is printed listing all types of analyses [illegible] computed, printed and plotted for this test.

When program control parameter [illegible] all raw [illegible] and z axis data are printed in counts. The frame [illegible] [illegible] data are computed and printed for all [illegible] [illegible] until 2 [illegible]

```
XD(1)=X(I,1) - X(I-1,1)
XD(J)=X(I,J) - X(I-1,J) - XD(1).
```

XD(1) is the range difference from the I^{th} frame and XD(J) is the variable minus range difference for the J^{th} variable and the I^{th} frame. The above are also computed and printed for the z axis data.

When code sheet parameter ICAM is greater than one (camera is on the sled) subroutine ROTATE is called to rotate, translate, and calibrate the x and z axis data. When ICAM is less than one, these x and z axis data are adjusted for shifts in the range reference reading and then converted from counts to feet (in the Main routine):

```
H1=X(I,1) - X(1,1)
H2=Z(I,1) - Z(1,1)
X(I,J) = (X(I,J) - H1) * CAL(J)
Z(I,J) = (Z(I,J) - H2) * CAL(J)
```

where CAL(J) is the calibration factor for the J^{th} variable (J=2 to 8). Next subroutine MEAN1 is called to compute and print the mean and standard deviation about the mean for the sled reference data. This provides an estimate of the film reading errors since the adjusted sled reference should be a constant.

When program control parameters IPC < 2 or IPA < 2, x and z axis motion relative to the sled are computed for variables 3 to 8 (or 7 and 8 for ITYPE=1):

```
XD(I)=X(I,J) - X(I,2)
ZD(I)=Z(I,J) - Z(I,2).
```

Subroutine SM is called to compute a moving eleven point (NP-11) quadratic least square fit to smooth the X and Z axis data. The smoothed data are stored in arrays XX(I,JJ) and ZZ(I,JJ) where JJ=J-2. As a result of the eleven point smoothing, five frames are lost at the beginning and end of the test data; this is true

each time the data are smoothed by subroutine [illegible]

are computed by subroutine [illegible]

smoothed data relative to the sled [illegible]

routine [illegible] is called [illegible]

for all variables [illegible].

The angle between the shoulder and [illegible]

for each frame using the above smooth data when [illegible]

parameter IPA [illegible] 2. The angle in radians [illegible]

$$H1=ZZ(I,3) - ZZ(I,[illegible]$$

$$H2=XX(I,3) - XX(I,[illegible]$$

$$XD(I)= \arctan (H1/H2)$$

where index 3 is shoulder data and index 1 is hip data in the XX and ZZ arrays. Angles XD(I) are adjusted [illegible] make them continuous. Subroutine [illegible] angular velocity in radians per second from [illegible] (NP=11) quadratic fit of the XD [illegible] data and angular acceleration in radians per second squared from an [illegible] quadratic fit of the velocity data. The angular data are printed and, for IPA=0, subroutine CPLT is called to generate CALCOMP plots of the angular velocity and acceleration versus time (IP=2). All above angular data are computed in a similar manner for head point 1 minus head point 2 data (indices 5 and 6 in arrays XX and ZZ).

Parameter M contains the number of sets of linear velocity and acceleration data to be computed for one variable (array ID) relative to another (array IR). For example, if ID(1)=3, and IR(1)=2, then for set M=1 the hip motion relative to the sled is computed for all available frames.

If M < 0 and IPL [illegible] 2, all data for variables J=2 to 8 are adjusted by subtracting the initial value as follows:

$$X(I,J)=X(I,J) - X(1,J)$$

$$Z(I,J)=Z(I,J) - Z(1,J)$$

where all x and z data have previously been [illegible] to feet. For each of the M sets the following are computed:

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] flow chart [illegible] this [illegible] is shown [illegible]

Error Diagnostics: [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

2.2.[illegible] [illegible]

Subroutine [illegible] generates a CALCOMP pl[illegible] versus z displacement with respect [illegible] the sled [illegible] parameters. [illegible] time versus angul[illegible] velocity and a[illegible] (c) time vers[illegible] velocity and acceleration [illegible] value of [illegible] CALCOMP plot [illegible] required to [illegible] the program.

[illegible]

For parameter IP=1, CPLT generates one [illegible] of [illegible] versus [illegible] for variable motion [illegible] the sled [illegible] are set by [illegible] data and [illegible] follows.

[illegible]

[illegible]

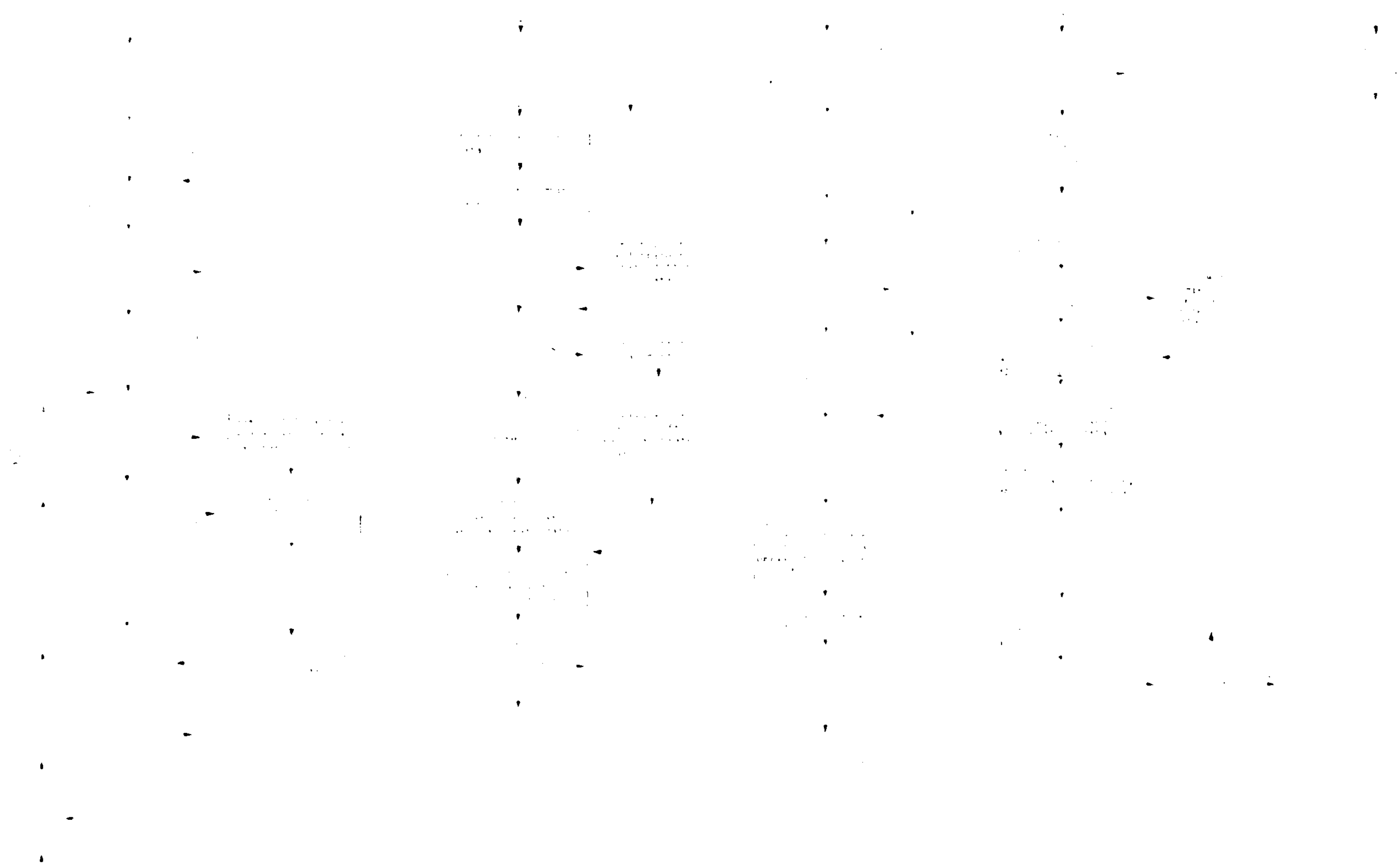


Figure 6. HIPPO Flow Chart.

(c) The [illegible]

(d) The X and [illegible]

The variables are [illegible] from indices [illegible] to be plotted [illegible] data are checked [illegible] values; if not, they [illegible] Subroutines LINE and [illegible] the legend on the graph.

For parameter [illegible] X array) in seconds [illegible] second and acceleration [illegible] time scaling is determined [illegible]

(a) the minimum [illegible] initial time value, X(1), adjusted [illegible] X(1);

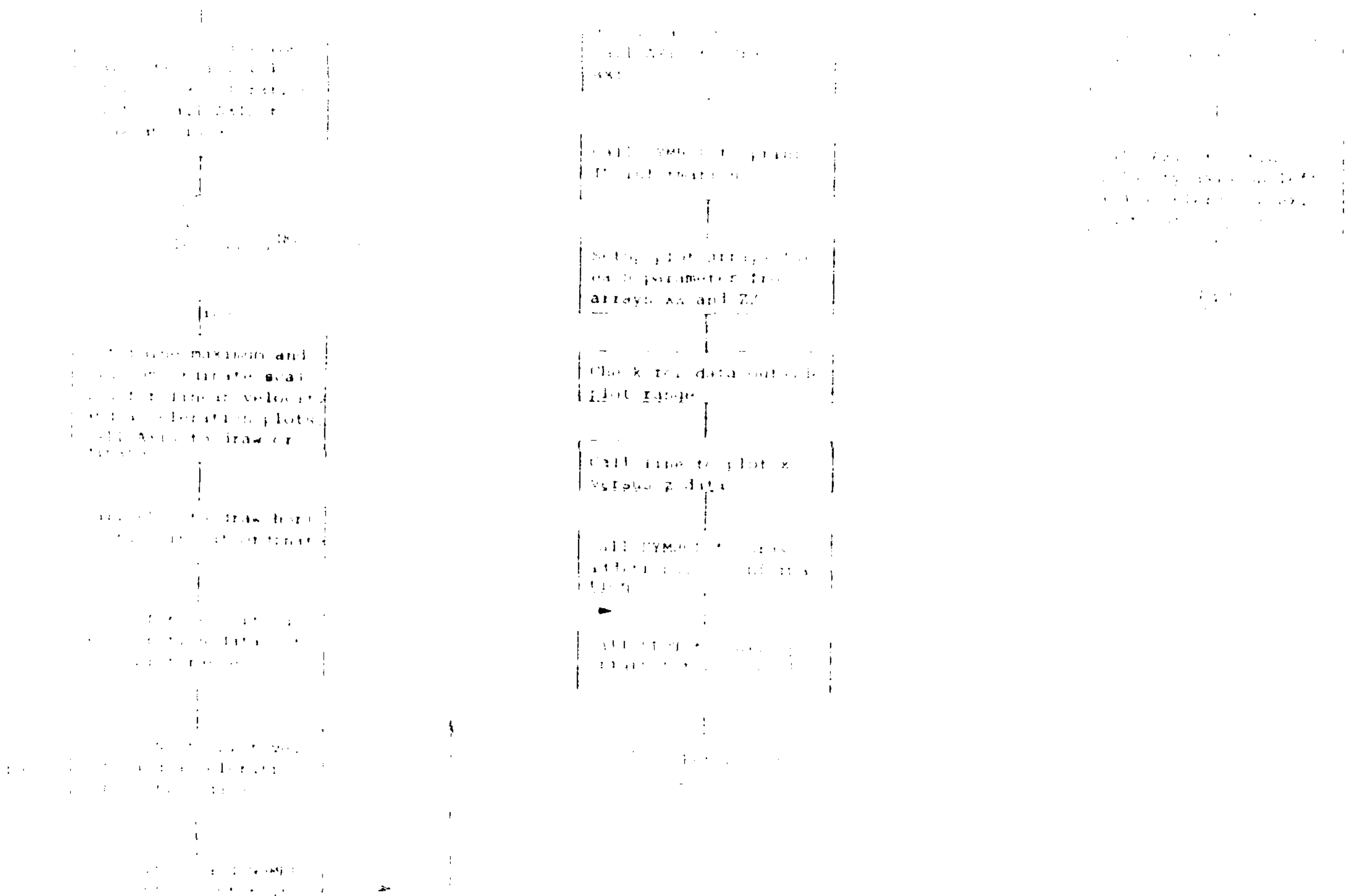
(b) the time increment per inch, [illegible]

(c) The time axis length (SX) is determined from DX and the total range X(N)-XMIN

SX=FLOAT(IFIX((X(N)-XMIN)/DX)+1).

The angular velocity and acceleration [illegible] inch scaling are set up by calling subroutine [illegible] which checks the data and sets values accordingly. The velocity scale is printed on the left side of the graph and the acceleration scale on the right side. Subroutines LINE and SYMBOL are called to plot the data and print the legend on the graph.

For parameter IP=3, [illegible] generates one plot [illegible] or X array) in seconds versus linear velocity [illegible] second and acceleration (Z) in G's. The time scaling is computed as per IP=2 above. The velocity and acceleration are [illegible] using the same ordinate [illegible]



[illegible] Chart.

[illegible] with [illegible]

[illegible] and [illegible]

[illegible] for this [illegible]

[illegible] statistics: [illegible]

[illegible] [illegible] array [illegible]

[illegible] and Labeled [illegible] Variables [illegible]

NP - number of points used in least square fit

I1 - first point used in composite plot

I2 - last point used in composite plot

XX - array of x axis displacement data

ZZ - array of z axis displacement data

ICAL - flag array which identifies defined data

ICAL(J) = 0 - J^{th} variable undefined

ICAL(J) = 1 - J^{th} variable is defined

HEADL - array containing variable names used in legend

TEST - test identification used in legend

IRX - flag used to setup composite plot X axis scale

DYLP - y increment per inch for linear plots

Subroutine Length: 1612_8

Labeled Common Length: 24_8

Blank Common Length: 7066_8

2.2.3 Subroutine SM(X, Y, YC, N, NP)

Subroutine SM is a smoothing routine which computes a quadratic least square fit of NP dependent variable data points (Y) to compute each smoothed data point (YC). Since NP data points are used to compute each smoothed point, M data points are lost at the beginning and end of array YC, where

$$M=(NP-1)/2.$$

Method

The first (MM) and last (NN) array indices for which YC(I) are computed are determined as follows:

$$MM=M + 1$$

$$NN=N - M$$

where M is defined above and N is the number of original displacement points in array Y. Subroutine QLSQ is called to compute the C_1, C_2, and C_3 coefficients for each of the I smoothed points which are then computed as follows:

$$YC(I)=C_1 * X(I)^2 + C_2 *X(I) + C_3.$$

A flow chart for this routine is shown in Figure 8.

Error Diagnostics: NONE

Subroutines Required: QLSQ

Argument List:

X = array of independent variable

Y = array of dependent variable

YC = array of smoothed dependent variable data

N = number of original displacement versus time data points

NP = number of points used to compute each smoothed data point

Subroutine Length: 75_8

2.2.4 Subroutine DERIV1 (X, Y, YP, N, NP, ID)

Subroutine DERIV1 computes the derivative (YP) of the dependent variable Y. A quadratic least square fit of NP points is used to compute each derivative point; thus K points are lost at the beginning and end of array UP:

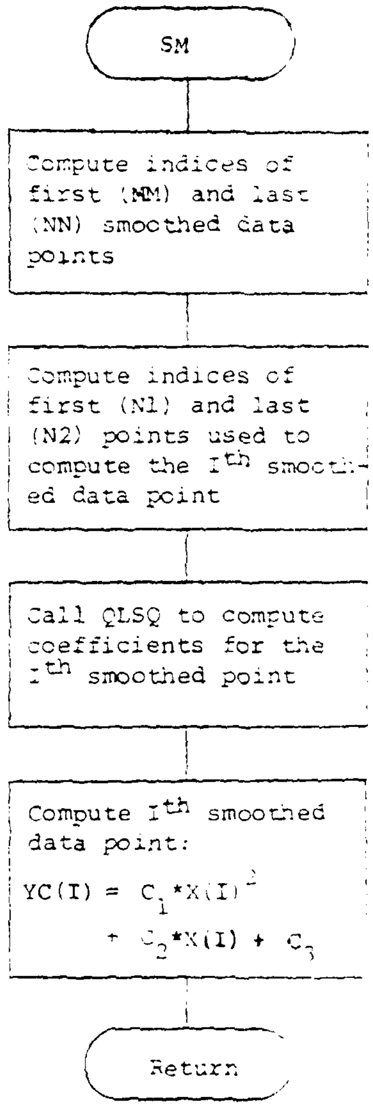


Figure 8. SM Flow Chart.

where

$$K = M + M * ID,$$

$$M = (NP - 1)/2,$$

ID = 1 for first derivative, and

ID = 2 for second derivative

Note that for ID = 1, array Y contains displacement data which have already been smoothed using a quadratic least square fit over NP points; thus, M points have already been lost from the original displacement data. For ID = 2, array Y contains first derivative (velocity) data which starts at array location Y(2*M + 1).

Method

The first (MM) and last (NN) array indices for which YP(I) are computed are determined as follows:

$$MM = K + 1$$

$$NN = N - K$$

where K and M are defined above and N is the number of original displacement data points. Subroutine QLSQ is called to compute the C_1, C_2, and C_3 coefficients for each of the I derivative points. The derivative YP(I) is then computed as follows:

$$YP(I) = 2* C_1*X(I) + C_2.$$

A flow chart for this routine is shown in Figure 9.

Error Diagnostics: NONE

Subroutine Required: QLSQ

Argument List:

X = array of independent variables

Y = array of dependent variables (displacement or velocity)

YP = array of derivative data

N = number of original displacement versus time data points

NP - number of points used to compute each derivative point

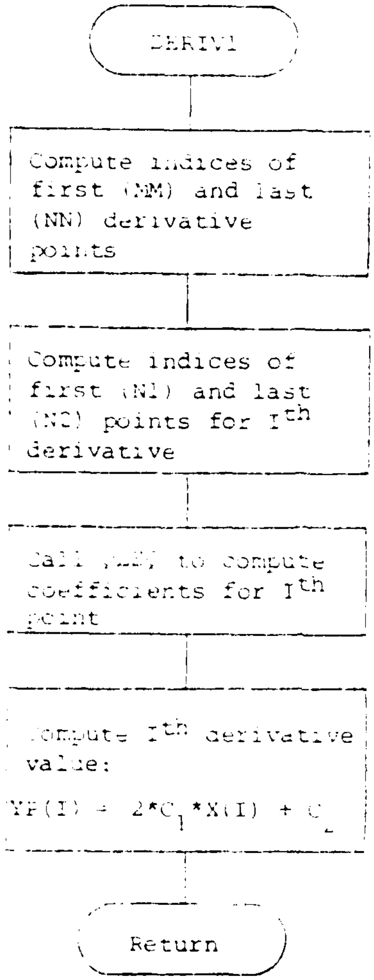


Figure 9. DERIV1 Flow Chart.

ID = 1 --array [illegible] ment data and array [illegible] will contain velocity data

ID = 2 --array [illegible] data and array Y will [illegible] acceleration [illegible]

Subroutine Length: 77_8

[illegible].5 Subroutine QLS2 (X, Y, N1, N2, C)

Subroutine QLS2 uses the method of least squares to compute the quadratic coefficients (C_1, C_2, and C_3) for an equation of the form:

$$Y = C_1 * X^2 + C_2 * X + C_3$$

for FN data points (FN = N2 - N1 + 1) from X and Y array indices N1 to N2. FN must be an odd integer $\geq$ 3.

Method

The independent variable X(I) is translated by a term FF, where

$$FF = X(NN),$$

$$NN = \frac{N1 + N2}{2}$$

and

$$XP(I) = X(I) - FF.$$

The quadratic equation in terms of the translated independent variable is

$$Y = A_1 * XP^2 + A_2 * XP + A_3.$$

The least square residuals are a minimum when the following equations are satisfied:

$$A_1 * \Sigma XP^4 + A_2 * \Sigma XP^3 + A_3 * \Sigma XP^2 = \Sigma XP^2 * Y$$

$$A_1 * \Sigma XP^3 + A_2 * \Sigma XP^2 + A_3 * \Sigma XP = \Sigma XP * Y$$

$$A_1 * \Sigma XP^2 + A_2 * \Sigma XP + A_3 * FN = \Sigma Y$$

where summations of XP and Y are computed for index I equal N1 to N2. Determinants are used to solve the above system of equations for the coefficients A_1, A_2, and A_3. The C_1, C_2, and C_3 coefficients are computed from A_1, A_2, and A_3 as follows:

$$C_1 = A_1$$

$$C_2 = A_2 - 2 * A_1 * FF$$

$$C_3 = A_3 + A_1 * FF^2 - A_2 * FF.$$

A flow chart for this routine is shown in Figure 10.

<u>Error Diagnostics:</u> NONE

<u>Subroutines Required:</u> NONE

<u>Argument List:</u>

X=array of independent variables

Y=array of dependent variables

N1=index of first point used in fit

N2=index of last point used in fit

C=array containing quadratic coefficients.

<u>Subroutine Length:</u> 134_8

2.2.6 Subroutine ROTATE(N,J1,IPR)

Subroutine ROTATE translates, rotates, and calibrates the on-board camera data stored in arrays x and z. All data are translated to a coordinate system through the sled range reference point (first x, z point for each time). The axis is then rotated so the angle between the sled range reference and the sled reference (second x, z point for each time) is the same for all time steps, i.e., all angles between the sled range reference and sled reference are the same as the angle at time zero. The data are then translated back to the initial coordinate system (at time zero).

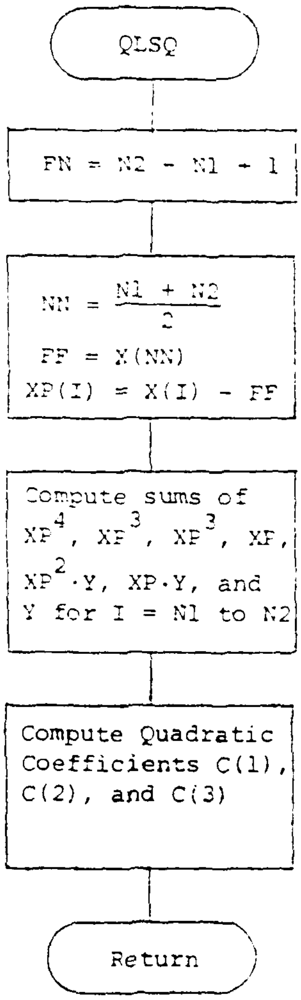


Figure 10. QLSQ Flow Chart.

Method

For the first time station, the range x and z data are subtracted from the sled reference x and z:

$$X1=X(1,2) - X(1,1)$$
$$Z1=Z(1,2) - Z(1,1) \quad .$$

These differences are used to compute the reference angle θ_R:

$$\theta_R=\arctan\ (Z1/X1)$$

If θ_R is less than zero, then

$$\theta_R=\theta_R + 360.$$

This is the reference angle between the range and sled reference points. For all other time stations, the axis through the range reference is rotated to make the angle between the range and the sled reference points the same as θ_R. Note that for this first time station none of the x and z array data are rotated or translated.

For time stations I=2 to N, the following are computed:

(a) All data (J=2 to 8) are translated to a coordinate system through the range reference as follows:

$$X(I,J)=X(I,J) - X(I,1)$$
$$Z(I,J)=Z(I,J) - Z(I,1)$$

(b) Angle θ_i is computed from the sled reference difference:

$$\theta_i=\arctan\ [Z(I,2)/X(I,2)]$$

If θ_i is less than zero, then

$$\theta_i=\theta_i + 360.$$

(c) Angle θ is the angle by which the I^{th} points have been rotated with respect to the initial θ_R:

$$\theta=\theta_i - \theta_R .$$

(d) The inverse rotation (or rotation by $-\theta$) is computed as follows for parameters J=2 to 8:

X(I,J)=X(I,J) * cosθ + Z(I,J) * sinθ
Z(I,J)= -X(I,J) * sinθ + Z(I,J) * cosθ

(e) The data points are then translated back to the initial range coordinate system (at time zero):

X(I,J)=X(I,J) + X(1,1)
Z(I,J)=Z(I,J) + Z(1,1)

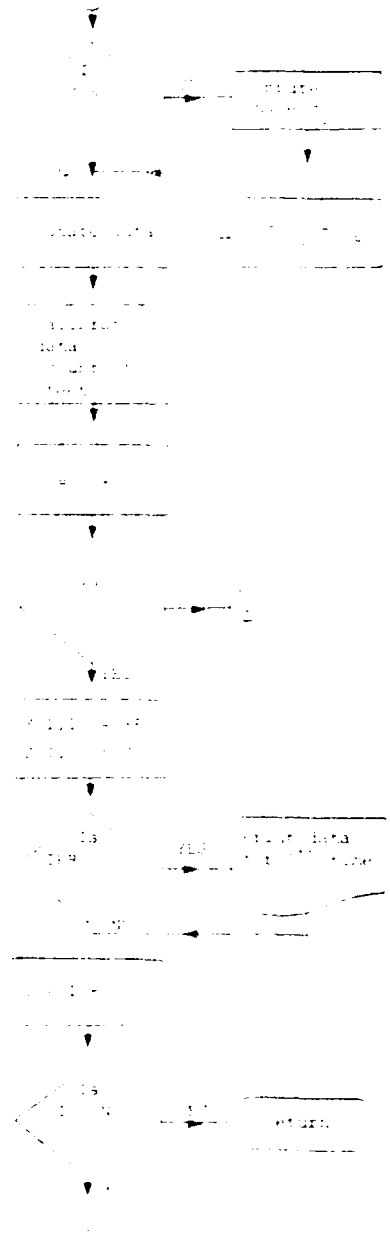
(f) All x and z data for parameters J=2 to 8 are converted from counts to feet:

X(I,J)=X(I,J) * CAL(J)
Z(I,J)=Z(I,J) * CAL(J)

This subroutine also prints a listing of frame number versus parameter x, z data in counts when IPR is less than one.

A flow chart for this routine is shown in Figure 11.

Error Diagnostics:	NONE
Subroutines Required:	NONE
Argument List:	N = number of displacement versus time data points
	J1 = index of first parameter after sled reference. For ITYPE=0, J1=3; for ITYPE=1, J1=2.
	IPR = print control parameter.
Blank COMMON Variables (used by this subroutine):	IFR = array containing frame numbers
	X = array of x displacement data
	Z = array of z displacement data



CAL = array of calibration data feet per count

XD = dummy array used to store data for printing

ZD = dummy array used to store data for printing

Subroutine Length: 250_8

Blank Common Length: 23434_8

2.2.7 Subroutine MEAN1 (N,X,Z)

Subroutine MEAN1 computes the mean and the standard deviation about the mean for x and z axis sled reference data.

Method

Compute the mean of the x and z axis data:

$$AVX = \frac{1}{N} \sum_{I=1}^{N} X(I)$$

$$AVZ = \frac{1}{N} \sum_{I=1}^{N} Z(I).$$

Then compute the standard deviation of the data about the mean x and z axis value:

$$SMX = \sqrt{\frac{\sum_{I=1}^{N} [X(I)-AVX]^2}{N-1}}$$

$$SMZ = \sqrt{\frac{\sum_{I=1}^{N} [Z(I)-AVZ]^2}{N-1}}$$

Finally, print the mean and standard deviation data on the standard output file.

A flow chart for this routine is given in Figure 12.

Error Diagnostics:	NONE
Subroutines Required:	NONE
Argument List:	N = number of x and z axis data points
	X = array of x axis data points
	Z = array of z axis data points
Subroutine Length:	116_8

2.2.8 Subroutine MEAN2 (N1, N2, DI, DC, XD, ZD, SMX, SMX2, SMZ, SMZ2)

Subroutine MEAN2 computes the mean and standard deviation of unsmoothed minus smoothed x and z axis data.

Method

The sums and sums of squares of the unsmoothed minus smoothed data are computed as follows:

$$SMX = \sum_{I=N1}^{N2} DI(I) - XD(I)$$

$$SMX2 = \sum_{I=N1}^{N2} [DI(I) - XD(I)]^2$$

$$SMZ = \sum_{I=N1}^{N2} DC(I) - ZD(I)$$

$$SMZ2 = \sum_{I=N1}^{N2} [DC(I) - ZD(I)]^2$$

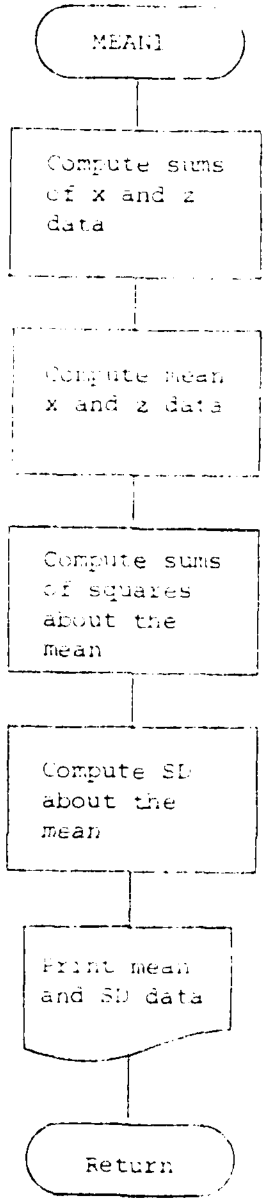


Figure 12. MEAN1 Flow Chart.

The variables used above are defined in the argument list below. The means (SMX and SMZ) and standard deviations (SMX2 and SMZ2) are then computed from these sums and sums of squares:

SMX=SMX/FNN

$$SMX2 = \sqrt{\frac{SMX2-(SMX)^2(FNN)}{FNN-1}}$$

SMZ=SMZ/FNN

$$SMZ2 = \sqrt{\frac{SMZ2-(SMZ)^2(FNN)}{FNN-1}}$$

FNN=N2-N1+1.

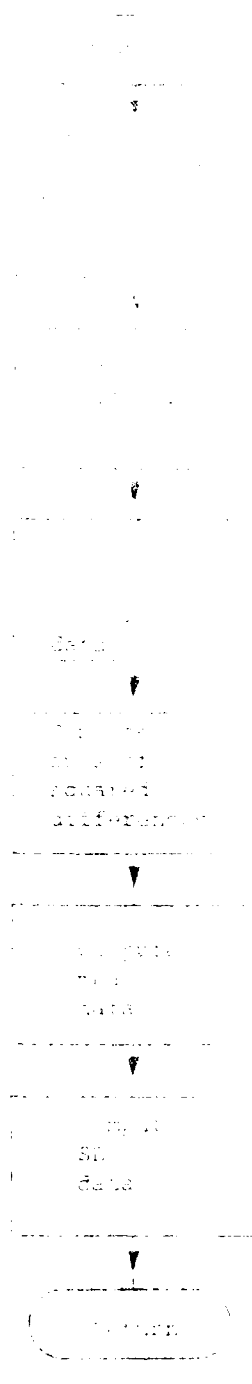
A flow chart for this routine is shown in Figure 13.

<u>Error Diagnostics:</u> NONE

<u>Subroutines Required:</u> NONE

<u>Argument List:</u>

N1	=	index of the first data point used in the summations
N2	=	index of the last data point used in the summations
DI	=	array of unsmoothed x axis data points
DC	=	array of unsmoothed z axis data points
XD	=	array of smoothed x axis data points
ZD	=	array of smoothed z axis data points
SMX	=	mean x axis data
SMX2	=	standard deviation of x axis data
SMZ	=	mean z axis data



SMZ2 = standard deviation of Z axis data

Subroutine Length: 76_8.

[illegible].2.9 Data Preparation for Input to HIFED

Preparation of data for input to HIFED consists of editing and digitizing. The editing function provides film frame-to-time conversion and PCS coordinates to plane of motion coordinates conversion factors. The digitizing function provides the frame-by-frame "reading" of the projected film frame coordinates. The references, or "standards," required to process the data are film time reference pulses and surveyed fiducials in two planes normal to the optical axis of the camera.

Timing of the film frames was accomplished by calculating the average film speed over a span of approximately 150 frames (300 msec).

The first frame in which the stroboscopic flash was observed was defined as t=0. The strobe, initiated by a time synchronizing pulse which was also recorded on the magnetic tape recordings, actually gives t_0 indication within 2.0 milliseconds accuracy at the nominal film speed of 500 frames per second with a 140° shutter. Since the flash is not observed in film frame -0001 and is observed in film frame 0000, it is apparent that it was initiated between the closing of the shutter on film frame -0001 and the closing of the shutter on film frame 0000. During most tests, the intensity of the first observed flash would indicate that it was initiated between the closing of the shutter on frame -0001 and the opening of the shutter on frame 000. If this is the case, the t_0 indication could be considered to be accurate to -0, +1.2 milliseconds, i.e.,:

$$\frac{360° - 140°}{360°} \times 2 \text{ msec} = 1.22 \text{ msec}.$$

Determination of conversion constants to be applied to the digitized readings of the anthropometric points on the subject required that the following be known.

(a) The distance, normal to the plane of symmetry of the subject, from that plane to each of two planes, parallel to the plane of symmetry, in which reference fiducials were marked.

(b) The distances, normal to the plane of symmetry of the subject, from that plane to each of the anthropometric points to be tracked.

(c) That the optical axis of the primary camera was normal to the plane of symmetry of the subject.

(d) The distances, between centers, of the reference fiducials mounted in each of the reference planes.

The coordinates of the reference fiducials in the farther and the nearer reference planes were digitized five times. The readings of these coordinates were then averaged and the digital distance between the averaged coordinates of each pair was calculated. Dividing each of these digital distances by the corresponding measured dimension between fiducials yielded conversion constants, in terms of "counts per foot", in two planes normal to the optical axis. Having determined these conversion constants, and having measured the distance between the parallel planes in which the fiducials lay, the distance along the optical axis from the focal point of the lens to each of these planes and the planes of symmetry could then be calculated. (See Figure 4)

Prior to each test run the breadth of the subject was measured at each tracking fiducial location with an anthropometer. Assuming that each subject was symmetrical, the distance from the plane of symmetry to each tracking fiducial was defined as one-half the measured breadth of the subject at each fiducial location. Conversion constants for each plane parallel to the plane of symmetry, thus normal to the optical axis in which a tracking fiducial lay, were then calculated by similar techniques.

The actual digitization of the photometric [illegible] [illegible]ished on a Producers Service Corporation model [illegible] [illegible] [illegible]. The magnification factor of the projector was [illegible] [illegible], giving a projected frame image of [illegible] x [illegible] [illegible] [illegible] were [illegible] to the reading crosshairs [illegible] [illegible] in such a manner that a displacement of [illegible] [illegible]-inch caused the associated optical encoder to [illegible] [illegible] the reading by one thousand counts.

[illegible] operator located the first frame [illegible] [illegible] [illegible] flash was observed and reset the frame [illegible] [illegible] optical center of the film frame was found by [illegible] [illegible] the vertical and horizontal dimensions of the [illegible] image. The operator then positioned the crosshairs [illegible] [illegible] reference fiducial and depressed the record switch [illegible] frame number and coordinates of the fiducial to be punched [illegible] paper tape and typed on the carriage of the teletype [illegible]. He then proceeded to position the crosshairs over the seat [illegible] reference fiducial. Again, depressing the record switch caused [illegible] coordinates to be recorded on the listing and the paper [illegible]. In this manner he would proceed to each of the other points [illegible] [illegible] in Paragraph 2.1, recording their coordinates, [illegible] [illegible] had been extracted from that frame.

After advancing the film to the next frame, the [illegible] [illegible] check the coordinates of the range and seat fiducials. [illegible] the frame-to-frame variation of these coordinates exceeded [illegible] counts he would again locate the optical center of the film [illegible] image before proceeding.

This procedure was repeated for each film frame until the [illegible] appeared to have attained a static position after the [illegible].

[illegible]

were added to the file. This file was then copied on the card punch and printer as a time saving measure in case the disk file should be accidentally purged.

At this point the program HIFPD could have been attached and executed; however, the normal procedure was to obtain the card files and submit them in the batch mode on an overnight schedule. This permitted the connect time to be used for read-in and editing of additional data files.

Descriptions of specific procedures are presented in later sections, and the composition of a deck assembled for a typical computer run is illustrated in Figure 14.

2.2.10 Description of Program HIFPD Input Data and Parameter Codes

I. Program Setup Cards

A) The first card in the setup deck must contain the date in columns 1 to 10; for example, 12 FEB 74 or FEB 11, 74 (only one date card per job).

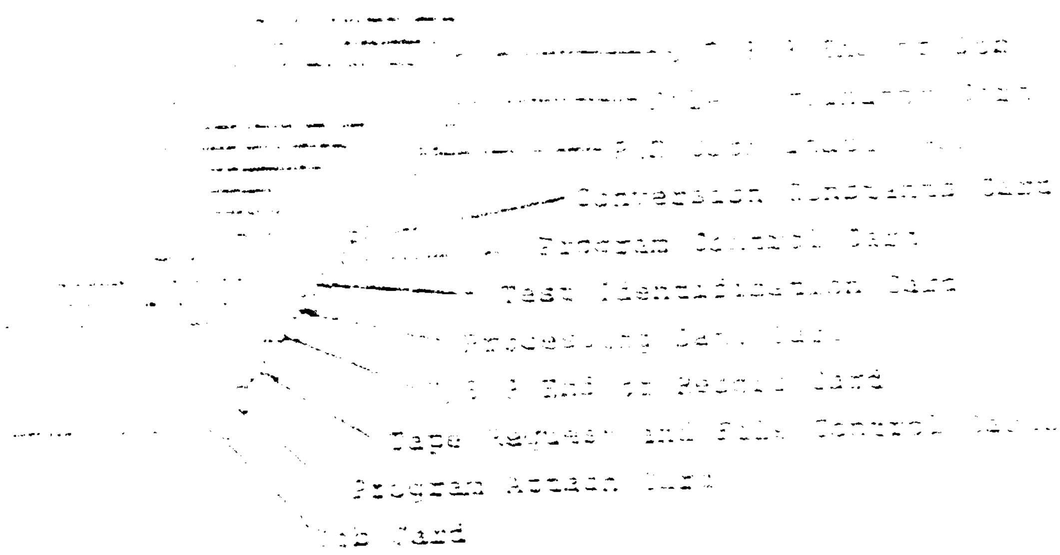
B) The following four or five cards are required for each test in the computer job:

Card Number 1

Column	Format	Data Description
1-80	8A10	80 columns of alphanumeric information which will be printed at the top of each page.

Card Number 2

1- 5	A5	**Test number**
6	I1	IRX--flag controlling polarity of x-axis data - blank or 0---no change 1---change sign of x-axis data
7	I1	IPR--flag controlling input data and difference printout - blank or 0---print data 1---omit printout


Conversion Constants Card
Program Control Card
Test Identification Card
Program Attach Card

Card Number [illegible] (Continued) [illegible]

Column Format [illegible]

[illegible]

13	I1	IPC--Flag [illegible] rolling [illegible] respect [illegible] data blank or 0--- [illegible] [illegible]---print only 2---omit these computations
14-16	I3	First frame [illegible] to the [illegible] frame [illegible]
17-19	I3	Last frame [illegible] sled plot [illegible]
20-21	I2	The number of [illegible] acceler[illegible]
23,24	[illegible]	[illegible] 21---sled relative to [illegible] [illegible]---[illegible] relative to [illegible]
26,27	[illegible]	[illegible]
29,[illegible]	[illegible]	[illegible]

[illegible]

Card Number 2 (Continued)

Column	Format	Data Description
59-60	I2	NP--number of data points used in the quadratic fit. NP must be an odd number ≥ 3; default is NP=11.
61-65	F5.0	DYLP--velocity and acceleration linear plot scale increment per inch (see parameter IPL). Default is 2.5, 5, 10, 20, or 30 depending on the range of the data.

Card Number 2A -- required only when IADJ > 0.

1-10	F10.0	Time calibration--number of frames per second. May be left blank if film speed is 500 frames per second.
11-20	F10.0	SLED calibration in counts per foot
21-30	F10.0	HIP calibration in counts per foot*
31-40	F10.0	KNEE calibration in counts per foot*
41-50	F10.0	SHOULDER calibration in counts per foot*
51-60	F10.0	ELBOW calibration in counts per foot*
61-70	F10.0	HEAD POINT 1 calibration in counts per foot
71-80	F10.0	HEAD POINT 2 calibration in counts per foot

NOTE: The decimal must be punched in the above data fields unless the data are integer and are right justified.

Card Number 4

1	I1	9 in column 1 to indicate the end of test input

NOTE: Cards 1, 2, and 3 are placed in front of the test deck and card 4 is placed after the last frame in the test.

C) The last card in the input deck (before the end of job card) contains the word "END" in columns 1 to 3.

*The calibration field for these variables must be zero or blank for ITYPE=1.

[illegible] Variable Code Identification

The following code versus variable name list is [illegible]

[illegible]

Code	Name
1	Range
2	Sled
3	Hip
4	Knee
5	Shoulder
6	Elbow
7	Head Point 1
8	Head Point 2

[illegible] Card Formats for the Test Input [illegible] Cards for [illegible]

Card Number 1

[illegible]	Format	Data Description
2- 5	I4	Frame number
6-12	I7	x reading in counts for Range data
13-19	I7	z reading in counts for Range data
20-26	I7	x for Sled
27-33	I7	z for Sled
34-40	I7	x for Hip
41-47	I7	z for Hip
48-54	I7	x for Knee
55-61	I7	z for Knee

Card Number 2

2- 5	I4	Frame number
6-12	I7	x reading in counts for Shoulder data
13-19	I7	z reading in counts for Shoulder data
20-26	I7	x for Elbow
27-33	I7	z for Elbow
[illegible]	[illegible]	x for Head Point 1

Card Number 2 (Continued)

Column	Format	Data Description
41-47	17	z for Head Point 1
48-54	17	x for Head Point 2
55-61	17	z for Head Point 2

IV. Card Formats for the Test Input Data Cards for ITYPE=1

Card Number 1

2- 5	14	Frame number
6-12	17	x reading in counts for Range data
13-19	17	z reading in counts for Range data
20-26	17	x for Sled
27-33	17	z for Sled
34-40	17	x for Head Point 1
41-47	17	z for Head Point 1
48-54	17	x for Head Point 2
55-61	17	z for Head Point 2

NOTE: For ITYPE=1, only 1 data card is read for each frame.

V. General Comments

A) If there are any errors in frame or card identification numbers, error statements will be printed at the top of the first output page for the test and all computations after the listing of the input data will be deleted.

B) A maximum of 300 frames (MAXN) will be read for each test. If the test input deck contains more than 300 frames, only the first 300 will be processed. This could be changed by changing MAXN and the array dimensions in the program.

C) If the calibration factor for a variable is missing flag ICAL(J) is set equal to zero and that variable will be deleted from the analysis.

D) An eleven point [illegible] used th[illegible] the [illegible] the value of NI on the [illegible].

The [illegible] for the [illegible] subroutine (CPLT). The x [illegible] the variable relative to the [illegible] ranges from -1.0 to 1.0 feet and [illegible] 4.0 feet. Any displacement [illegible] to the [illegible].

F) Program [illegible] IADJ [illegible] June 1977. IADJ controls [illegible] ment factors. When IADJ is [illegible], [illegible] omitted from the test. When [illegible] from setup card number [illegible] immediately after input [illegible] change). Setup card [illegible] when IADJ [illegible] 0.

G) The following items were [illegible] since December 1978:

(1) The mean and standard [illegible] mean are [illegible] after all adjustments [illegible] data [illegible].

(2) The mean and standard dev[illegible] differen[illegible] of data are [illegible] of data requested [illegible]

(4) The Vel [illegible] Acc [illegible] ment per inch (DY) has been [illegible] may now be set [illegible] the [illegible] the DYIP [illegible] DY will be set [illegible] 30 depending on the [illegible] DYLI is defined [illegible] the [illegible] (Card #2, Col. 61-65), [illegible] to DYIP even if [illegible]

7. [illegible] RESTRAINT SYSTEM DYNAMICS [illegible] COMPARISON

This report describes and [illegible] tem employed to collect and reduce data [illegible] anthropometric points on human subjects [illegible] exposed to laboratory simulations of [illegible] impact [illegible]

The primary objectives of the [illegible] were:

- [illegible]

- To determine the influence of [illegible] of restraint harnesses upon the [illegible] responses of the human body.

- To compare the measured inertial and [illegible] responses of the human body to [illegible] Articulated Total Body Model.

- To provide data to improve [illegible] culated Total Body Model [illegible] $-G_x$ impact environments.

[illegible]

Each of the volunteer subjects was exposed to each impact acceleration level three times; once with the rigid harness, once with an operational harness, and once with a nylon harness. The dummy tests which were evaluated consisted of three exposures to $-6\ G_x$ impacts and three exposures to $-10\ G_x$ impacts. The dummy was restrained by the operational harness during all six exposures.

The impact environments were developed on the Horizontal Impulse Accelerator Facility located in Building 824 at Wright-Patterson Air Force Base, Ohio. The tests were conducted by the Aerospace Medical Research Laboratory, Biomechanical Protection Branch (AMRL/BBP) (known at the time as Impact Branch, AMRL/BBI, during the period September 1976 - June 1977.

[illegible] Requirements

The anthropometric points specified to be tracked were the head, the shoulder, the elbow, the hip, and the knee. A second point on the head was also specified for the purpose of tracking its angular displacement relative to the first.

In accordance with Recommended Practice SAE J[illegible]8, SAE Handbook, 1975, the following points were specified to be marked with fiducials.

Head (Point 1)	The Trageon.
Head (Point 1) (Alternate)	A point approximately three (3) inches above the trageon.
Head (Point 2)	Outside corner of 9 Transducer Accelerometer Pack (9TAP) common to all three legs (Figure 15).[1]
Shoulder	The most lateral projection of the acromion process of the scapula.
Elbow	The most lateral projection of the humeral condyle.
Wrist	The most prominent projection of the stylion.

[1] Prior to Test 987 (23 Sept., 1976) a triaxial accelerometer was used [illegible]


Pretest
Tracker

were [illegible]
the impact [illegible]
[illegible]
mid-third [illegible]

coordinate [illegible]
eration [illegible]
velocities [illegible]
time histories of the head [illegible]

2.3.2 Photometric [illegible]

[illegible]

References [illegible]

[illegible]

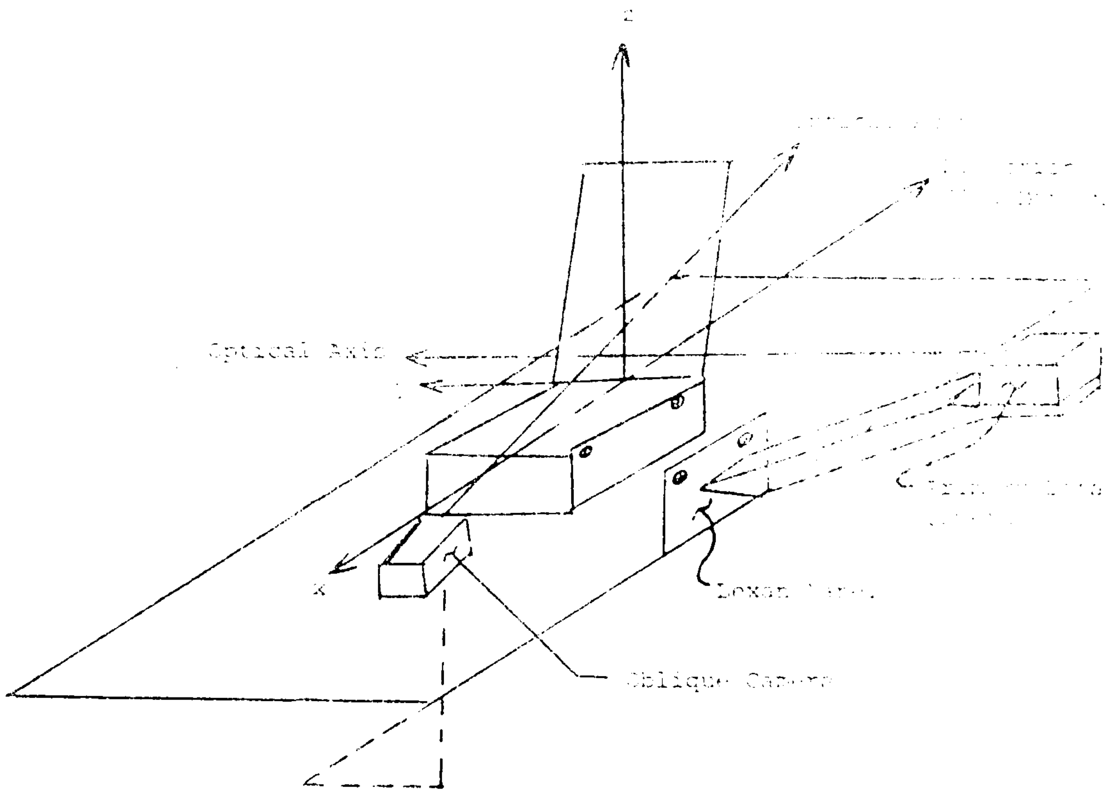


Figure 16. RSD(N/O/R) Seat Coordinate System and Onboard Camera Locations.

... al point at ...

... camera was mounted ... w ... focal point ... 45.35, 52.75). The ... was ... at an azimuth of 147 degrees ... from above. The roll attitude ... the optical axis.

... additional cameras were mounted ... with its focal point at prerest ... coordinate system prior to initiation of the event) (-12.45, -115.4, 28.8). This camera backup ... a malfunction of the primary data camera might ... and offboard camera was mounted above the accelera- ... to provide a frontal view of the subject through the event. The third ... mounted over head ... 14.50 ft above the ...

... Acquisition

... acquisition mission consisted of three ...

... documentation of anthropometric measurements of each subject.

... tracking fiducial application, measurement, and documentation.

... recording of the tracking fiducials during the impact and response events.

... anthropometry of each subject was measured and docu- ...

... tracking fiducial application, measurement and documenta- ... accomplished prior to each test run by the NBDL repre- ... Tracking fiducials were located as follows.

... medical treatment room, prior to the pretest ... acromion process of the scapula, lateral ... humeral condyle, stylion, and the lateral ... femoral condyle, all on the left ... palpation. At each ...

[illegible]

[illegible] used with [illegible] that they were [illegible]

[illegible] Tables [illegible]

[illegible] instrumentation [illegible] of the [illegible] one hundred [illegible]

[illegible]

TABLE 1

DEFINITIONS OF PRETEST DATA ITEMS

Item	Definitions
RS	Restraint Harness Material
GN	Nominal Impact Acceleration ($-G_x$)
RN	Test Number
DT	Date of Test (Year, Month, Day)
1	Weight (Kg)
2	Height of head band fiducial above sled deck
3	Height of shoulder above sled deck
4	Height of iliac crest above sled deck
5	Trageon to 9TAP origin
6	Trageon to headband fiducial distance
7	Shoulder to elbow distance
8	Elbow to wrist distance
9	Hip to iliac crest distance
10	Hip to knee distance
11	Mid-thigh to knee distance
12	Knee to ankle distance
13	Breadth at trageons
14	Breadth at shoulders
15	Breadth at elbows
16	Breadth at hips
17	Breadth at knees
18	Breadth at ankles
19	Mid-shoulder height. Distance along seat back plane from line of intercept of seat pan plane and seat back plane to a line normal to the seat back and tangent to the upper surface of the shoulder at the centerline of the left shoulder strap.

SUMMARY OF [illegible] DATA, [illegible]

	NYLON			OPERATIONAL			FIELD				
[illegible]	[illegible]	8	10	[illegible]	8	10	[illegible]	8	10		
[illegible]	15[illegible]	1158	1056	10[illegible]7	1022	969	1012	1202	1143		STANDARD
[illegible]	761215	770502	761116	770406	761103	760518	761019	770325	770215	MEAN	DEVIATION
1	75.51	76.87	76.19	76.[illegible]	75.28	76.42	74.15	78.00	77.19	76.24	1.15
2	107.56	105.44	105.84	106.26	107.34	105.76	106.54	105.00	106.14	106.24	.83
3	80.64	79.74	79.76	79.84	80.54	79.96	78.44	78.00	81.54	79.82	1.08
4	44.34	44.04	43.64	43.76	43.74	43.44	42.44	41.80	43.94	43.46	.62
5	12.60	13.50	12.80	13.60	12.50		12.70	12.90	13.40	13.00	.43
6	7.94	6.35	6.67	8.23	9.84	6.19	6.98	7.30	6.67	7.35	1.16
7	30.18	29.21	27.94	28.69	28.89	29.53	28.26	29.53	29.84	29.17	.78
8	25.72	25.40	25.72	24.76	25.40	25.08	25.08	25.72	25.08	25.33	.35
9	12.70	12.26	11.75	12.70	12.70	9.84	11.75	14.29	12.70	12.30	1.19
10	41.91	42.74	42.86	41.28	40.64	43.50	41.59	42.54	40.96	42.00	.97
11	25.40	25.40	25.40	25.40	25.24	22.86	25.40	25.72	25.40	25.14	.86
12	44.45	42.54	42.86	43.18	42.54	43.82	43.18	42.86	43.82	43.25	.65
13	14.80	15.30	15.40	14.90	15.30	14.80	15.30	15.40	15.60	15.20	.29
14	42.50	43.80	44.30	44.00	43.50	43.00	43.80	43.00	42.80	43.39	.61
15	55.90	56.30	57.70	56.10	55.10	52.60	56.70	56.40	56.50	55.92	1.42
16	39.00	38.40	38.80	38.50	39.20	36.60	37.40	37.70	39.80	38.39	.99
17	27.90	34.70	29.40	31.00	27.50	32.10	31.20	37.80	29.70	31.26	3.20
18	18.80	33.00	21.20	20.60	20.10	24.50	28.70	37.20	25.70	25.53	6.33
19	60.96	61.91	61.91	61.64	62.23	62.23	60.32	61.28	61.28	61.52	.83

TABLE 3

SUMMARY OF PRETEST DATA, SUBJECT A22

SUBJECT A 22

RS	NYLON			OPERATIONAL			RIGID				
GN	6	8	10	6	8	10	6	8	10		
RN	1102	1157	1071	1018	1041	993	1148	1138	1085		
DT	770122	761202	761210	761026	761118	760928	770216	770203	770106	MEAN	STANDARD DEVIATION
1	81.63	82.99	82.54	80.27	82.09	80.61	81.63	82.09	83.22	81.90	.99
2	110.94	110.64	111.54	111.94	111.14	109.54	110.54	109.80	111.24	110.81	.78
3	82.84	83.24	82.94	83.04	82.24	83.14	83.74	78.80	83.44	82.71	1.17
4	44.64	44.54	46.24	43.84	45.14	45.54	44.44	40.50	45.24	44.46	1.64
5	14.70	14.10	14.60	14.40	14.10		14.20	13.50	14.70	14.29	.41
6	6.98	6.67	8.26	8.26	6.35	6.67	7.62	8.89	7.78	7.50	.88
7	30.80	31.43	31.12	31.12	31.12	32.07	32.12	30.80	31.75	31.26	.42
8	27.30	26.99	26.67	26.67	26.67	26.99	26.67	26.99	26.67	26.85	.23
9	13.97	12.38	13.97	13.02	12.70	12.38	12.70	14.13	13.34	13.28	.70
10	44.77	46.36	46.36	43.50	44.13	44.45	43.82	44.77	42.23	44.49	1.31
11	24.92	25.40	25.40	25.40	25.40	24.76	25.40	25.40	25.08	25.24	.25
12	45.40	44.45	45.03	44.13	46.04	43.82	44.13	44.77	45.40	44.80	.73
13	14.50	14.60	14.40	14.70	15.80	14.50	14.80	14.60	14.60	14.77	.42
14	46.10	44.90	45.90	46.30	46.20	45.70	44.80	45.10	45.20	45.58	.58
15	53.70	54.50	55.90	55.00	54.10	52.80	55.60	55.20	52.70	54.39	1.16
16	39.20	38.70	39.60	36.60	38.60	38.00	38.50	39.20	39.30	38.86	.50
17	32.80	31.30	35.40	38.50	35.30	32.30	37.80	35.70	37.60	35.19	2.58
18	35.20	33.70	36.30	35.90	35.10	33.00	36.80	37.20	37.60	35.64	1.55
19	63.42	64.14	64.77	64.14	64.45	62.23	64.77	63.50	64.14	64.00	.78

TABLE [illegible]

SUMMARY OF PRETEST DATA, SUBJECT A[illegible]

[illegible]	N Y L O N			O P E R A T I O N A L			[illegible]				
[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]	10	[illegible]	8	10		
SN	1036	1077	1062	116[illegible]	578	1153	1207	1092	1080		STANDARD
ID	[illegible]	770104	761214	770516	761016	770201	770401	761015	761156	MEAN	DEVIATION
1	[illegible].00	101.[illegible]	104.62	99.77	96.27	99.32	99.32	97.96	99.72	99.66	1.16
2	1[illegible].24	111.44	109.14	111.24	108.64	110.94	111.04	108.14	108.54	110.[illegible]	1.32
3	86.88	85.44	85.76	86.54	85.14	87.44	88.24	84.74	85.54	86.14	1.75
4	44.[illegible]	44.44	44.84	44.04	44.64	45.34	45.14	44.44	45.04	44.57	.5[illegible]
5	15.2[illegible]	15.10	14.20	14.80		14.30	13.90	14.20	14.00	14.52	.46
6	8.8[illegible]	8.89	7.94	8.57	8.10	8.57	7.98	6.98	7.78	6.16	.[illegible]
7	[illegible]	31.12	31.75	31.75	31.43	30.80	31.75	32.07	31.43	31.8[illegible]	1.00
8	[illegible].41	27.30	27.34	27.62	28.89	27.90	27.94	27.94	27.62	27.90	.47
9	11.[illegible]	12.70	12.06	12.06	13.34	12.06	12.38	12.70	11.11	12.22	.[illegible]
10	52.07	48.58	49.21	48.58	47.90	49.21	46.04	46.99	46.36	48.44	1.83
11	25.40	25.08	25.24	25.40	25.40	25.24	26.04	25.40	25.56	25.42	.27
12	48.[illegible]	47.62	47.94	48.26	47.94	48.58	48.26	47.94	48.58	48.21	.37
13	1[illegible].80	14.60	14.70	14.80	14.30	14.50	14.40	14.80	14.50	14.67	.5[illegible]
14	45.[illegible]	45.00	46.20	45.40	47.[illegible]	45.70	44.70	45.40	46.10	45.77	.82
15	54.60	57.60	53.20	56.[illegible]	59.80	55.20	53.70	56.10	55.30	5[illegible].26	2.05
16	37.20	42.[illegible]	41.20	41.96	42.50	41.90	40.00	41.74	42.50	41.56	1.73
17	34.80	[illegible]	33.70	37.00	34.40	33.50	34.20	35.[illegible]	31.70	34.15	1.[illegible]
18	35.40	34.30	35.50	38.50	36.50	33.60	38.00	35.90	32.00	3[illegible].47	1.5[illegible]
19	[illegible]	66.3[illegible]	65.72	66.99	64.45	66.68	66.30	66.04	64.61	65.88	.95

TABLE 5

SUMMARY OF PRETEST DATA, SUBJECT B4

[illegible]

[illegible]	NYLON			OPERATIONAL			RIGID				
[illegible]	6	8	10	6	8	10	6	8	10		
[illegible]	1077	1102	1205	1317	1203	1227	1256	1328	1153		STANDARD
[illegible]	770104	770315	770401	770310	770325	770415	770428	770617	770301	MEAN	DEVIATION
1	74.83	75.19	75.74	72.54	76.19	75.74	76.64		75.74	75.46	1.26
[illegible]	108.34	109.36	111.54	110.64	113.14	112.24	112.44	110.74	111.14	111.10	1.07
[illegible]	81.24	82.64	83.74	82.74	80.24	83.74	84.84	83.44	83.24	83.20	.96
4	42.74	42.64	44.04	44.74	44.64	44.54	42.74	43.54	44.44	43.82	.94
[illegible]	13.50	14.10	13.40	14.90	13.30	13.70	13.80	13.90	13.10	13.73	.57
[illegible]	[illegible]	3.98	7.62	11.74	8.57	9.21	8.57		8.26	8.15	1.42
7	29.53	31.12	31.74	30.48	30.88	32.07	31.45		30.80	31.06	.73
[illegible]	27.30	[illegible]	26.35	28.58	26.99	26.04	26.35		26.04	26.74	.86
[illegible]	13.97	14.23	13.63	14.10	15.88	14.60	14.60		15.56	14.64	.75
1[illegible]	46.08	[illegible]	44.13	43.50	45.98	45.06	46.67		43.18	44.65	[illegible]
11	25.[illegible]	[illegible]	15.30	16.04	15.40	15.72	25.40		25.40	25.52	.34
12	[illegible]	[illegible]	[illegible]	47.62	46.54	46.67	47.31		46.54	46.87	.44
13	14.[illegible]	[illegible]	14.[illegible]	13.96	14.50	14.[illegible]	14.40	14.00	14.30	14.51	[illegible]
[illegible]	44.[illegible]	[illegible]	[illegible]	46.[illegible]	44.00	43.70	42.90	43.[illegible]	43.90	43.00	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54.60	52.80	52.[illegible]	[illegible]	52.66	1.03
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	38.70	36.20	37.00	37.[illegible]	39.30	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.60	38.80	41.[illegible]	40.00	39.11	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41.[illegible]	26.[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	46.27	.8[illegible]

TABLE 6

SUMMARY OF PRETEST DATA, SUBJECT B22

SUBJECT B 22

RS	NYLON			OPERATIONAL			RIGID				
GN	6	8	10	6	8	10	6	8	10		
RN	1044	1154	1070	1228	1180	1137	1086	1042	1150		
DT	761130	770301	761216	770415	770315	770203	770106	761118	770217	MEAN	STANDARD DEVIATION
1	85.71	85.82	85.94	85.14	85.83	86.17	86.62	85.71	86.16	85.90	.41
2	114.64	114.04	112.94	114.04	114.04	114.34	113.34	114.24	113.64	113.92	.53
3	87.84	87.54	88.64	87.54	88.44	87.84	87.64	88.24	87.44	87.88	.44
4	45.24	44.84	44.34	45.44	44.94	44.14	43.84	44.14	44.24	44.57	.56
5	13.90	12.50	13.40	13.30	12.40	13.70	13.80	13.10	13.60	13.29	.55
6	7.94	7.94	6.98	6.99	8.26	9.21	8.26	7.62	7.94	7.90	.68
7	31.43	32.39	32.38	32.70	32.70	31.75	31.75	30.60	32.39	32.03	.64
8	26.87	26.67	28.89	26.99	26.67	26.35	26.35	26.35	26.35	26.81	.81
9	13.97	14.92	13.34	15.24	13.65	15.92	12.70	13.97	14.29	14.22	1.00
10	45.08	45.72	45.72	44.77	44.13	43.82	42.86	42.54	42.55	44.13	1.28
11	25.40	25.24	25.40	25.24	25.40	25.08	25.40	25.72	25.40	25.36	.17
12	47.62	46.99	47.31	46.99	46.36	46.99	47.31	47.94	46.99	47.17	.45
13	14.30	14.20	14.90	14.70	14.70	14.30	14.60	14.50	14.30	14.50	.24
14	43.10	43.30	42.80	42.80	42.70	43.00	43.20	43.20	42.30	42.93	.32
15	53.80	55.90	56.30	54.80	56.70	56.40	55.20	52.20	53.80	54.99	1.51
16	38.70	40.20	40.40	39.00	40.40	42.20	40.80	41.10	40.50	40.37	1.05
17	32.90	35.20	33.00	32.60	34.60	34.90	34.20	34.90	32.90	33.91	1.05
18	29.20	37.50	36.60	39.10	38.30	38.50	37.10	38.10	35.60	36.67	3.00
19	68.58	67.63	68.26	67.94	67.31	67.94	67.63	66.99	67.63	67.77	.48

TABLE 7

SUMMARY OF PRETEST DATA, SUBJECT B3

Subject B3

ES	NYLON			OPERATIONAL			RIGID				
SN	6	8	10	6	8	10	6	8	10		
RN	1089	1103	1135	980	1028	1072	1017	1144	1037		
DT	770107	770120	770201	760915	761104	761216	761026	770215	761117	MEAN	STANDARD DEVIATION
1	79.37	81.18	80.27	84.35	82.09	81.63	82.54	80.27	82.09	81.53	1.48
2	103.84	104.34	104.24	102.74	104.34	103.24	105.64	103.74	104.14	104.03	.81
3	77.94	75.84	78.54	78.44	78.04	78.44	78.04	78.04	77.34	77.85	.84
4	44.34	41.84	42.24	41.64	43.14	42.04	42.74	43.74	44.34	42.90	105
5	14.20	13.10	14.90	15.90	14.00	13.90	14.40	11.30	13.70	14.16	.85
6	8.89	7.62	9.21	8.26	8.89	8.10	8.89	7.94	7.94	8.42	.56
7	28.56	28.89	29.84	30.80	29.21	30.43	29.53	29.21	28.89	29.49	.75
8	25.40	25.72	24.13	25.40	26.04	24.76	25.72	25.08	28.26	25.61	1.15
9	12.38	10.80	11.11	10.32	12.38	10.80	12.38	15.24	12.38	11.98	1.46
10	46.04	47.62	48.90	49.21	46.67	44.77	47.94	44.13	44.13	[illegible]	1.56
11	25.40	25.40	25.40	25.40	25.40	25.40	25.40	25.40	25.40	25.40	.00
12	[illegible]	44.45	42.86	43.82	44.61	44.13	43.50	45.08	45.40	[illegible]	[illegible]
[illegible]	[illegible]	14.50	14.40	14.50	14.50	14.50	14.40	14.70	14.70	[illegible]	.21
[illegible]	[illegible]	47.80	48.40	44.10	46.30	48.40	46.70	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	60.20	55.90	59.40	54.70	[illegible]	55.90	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	40.30	40.10	40.80	40.50	[illegible]	40.80	40.70	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	32.70	[illegible]	32.60	39.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36.30	37.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	59.37	59.06	59.06	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 8

SUMMARY OF PRETEST DATA, SUBJECT C1

[illegible]

[illegible]	NYLON			OPERATIONAL			RIGID				
[illegible]	6	8	10	6	8	10	6	8	10		
[illegible]	1134	1034	1067	1020	977	1151	1091	1003	1157		STANDARD
[illegible]	770201	770114	761215	761102	760914	770217	770107	761098	770302	MEAN	DEVIATION
1	74.15	75.08	75.74	75.28	73.92	74.38	75.06	73.47	75.74	74.76	.81
2	108.54	108.94	109.54	110.44	107.24	110.94	110.24	109.74	109.54	109.44	1.13
3	79.74	81.34	82.94	81.84	78.94	81.74	82.74	82.14	82.44	81.52	[illegible]
4	43.34	43.24	44.44	43 34	42.94	45.34	44.44	44.74	44.54	44.04	.84
5	14.00	13.45	13.30	12.70		12.80	13.30	13.20	13.60	13.29	.42
6	8.57	7.94	7.94	8.89	9.68	8.89	9.21	6.67	9.84	8.63	.99
7	30.35	31.12	32.07	30.48	30.96	31.43	30.48	31.75	31.75	31.22	.57
8	27.30	26.67	26.99	27.30	25.72	26.99	26.99	26.83	27.30	26.90	.49
9	12.70	12.06	13.02	12.38		13.34	12.38	13.02	12.70	12.70	.42
10	45.08	48.90	46.04	45.72	49.21	46.67	45.09	44.45	46.36	46.39	1.66
11	25.40	25.40	25.40	25.08	23.97	25.40	25.40	25.08	25.40	25.17	.47
12	46.99	45.40	45.72	46.36	46.36	45.40	46.99	46.67	47.31	46.36	.71
13	14.10	14.30	14.00	14.40	14.10	13.90	13.90	14.20	14.10	14.11	.17
14	[illegible]	44.20	44.10	44.80	44.40	44.80	44.50	44.10	44.70	44.51	.33
15	[illegible]	[illegible]	57.40	57.40	55.90	56.20	56.10	54.30	55.50	55.87	1.09
16	[illegible]	[illegible]	38.80	37.70	38.50	38.30	38.20	37.50	38.20	38.26	.48
17	[illegible]	[illegible]	36.70	37.80	33.70	32.70	27.90	36.10	28.90	32.87	3.49
18	[illegible]	29.50	35.90	36.60	33.39	33.70	27.40	35.90	30.50	32.79	3.13
19	[illegible]	[illegible]	62.86	63.50		63.50	62.86	62.23	62.86	63.02	[illegible]

TABLE 9

SUMMARY OF PRETEST DATA, SUBJECT C2

[illegible]	NYLON 6	NYLON 8	NYLON 10	OPERATIONAL 6	OPERATIONAL 8	OPERATIONAL 10	RIGID 6	RIGID 8	RIGID 10		
[illegible]	[illegible]	1039	1011	1056	992	1023	1201	1001	1140		STANDARD
[illegible]	[illegible]	761117	761019	761202	760928	761103	770325	761015	770203	MEAN	DEVIATION
1	[illegible]	81.18	80.39	80.50	82.99	81.18	82.69	81.07	81.63	81.22	.93
[illegible]	[illegible]	108.44	108.04	109.34	106.94	110.04	111.34	106.54	110.24	108.98	1.61
[illegible]	[illegible]	[illegible]	81.04	82.14	81.44	81.54	80.04	80.94	81.34	81.36	.65
[illegible]	[illegible]	44.34	44.14	43.94	43.64	43.94	44.64	43.64	44.84	44.25	.53
[illegible]	[illegible]	13.70	14.20	14.30	14.80	13.20	13.90	14.50	13.30	14.02	.54
[illegible]		[illegible]	8.89	8.57	7.94	8.26	8.89	6.19	7.94	7.88	1.06
[illegible]	[illegible]	[illegible]	34.29	33.18	33.02	33.02	32.70	32.39	34.29	33.29	.66
[illegible]	[illegible]	[illegible]	28.26	27.30	26.67	27.62	27.62	27.94	27.30	27.62	.50
[illegible]	[illegible]	13.97	13.65	13.34	13.97	13.65	13.65	12.70	14.29	13.51	.62
[illegible]	[illegible]	[illegible]	47.62	46.67	46.58	47.94	46.99	46.04	46.04	47.03	.87
[illegible]	[illegible]	[illegible]	27.94	25.72	25.40	25.40	25.40	25.68	25.08	25.61	.90
[illegible]	[illegible]	[illegible]	48.58	47.94	47.31	47.62	47.62	48.90	47.94	47.94	[illegible]
[illegible]	[illegible]	[illegible]	14.50	14.20	13.80	14.60	14.50	15.10	14.60	14.47	.39
[illegible]	[illegible]	[illegible]	45.10	45.10	44.60	43.90	44.20	46.70	48.20	45.43	[illegible]
[illegible]	[illegible]	[illegible]	53.90	54.80	57.10	54.90	51.50	57.20	53.50	54.06	2.16
[illegible]	[illegible]	[illegible]	37.90	38.10	38.40	39.10	39.10	37.60	39.50	38.59	.62
[illegible]	[illegible]	[illegible]	[illegible]	35.80	37.60	33.50	[illegible]	32.20	35.20	34.52	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	36.80	37.40	35.29	[illegible]	32.10	35.60	35.10	1.57
[illegible]	[illegible]	[illegible]	[illegible]	61.91	62.23	63.18	[illegible]	63.50	63.18	[illegible]	[illegible]

TABLE [illegible]

SUMMARY OF [illegible] TEST DATA, [illegible]

				1 30	1119						
	[illegible]	[illegible]	[illegible]	70167	77502	26626	[illegible]	.117	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	87.98	87.76	88.66	89.12	[illegible]	[illegible]	[illegible]	[illegible]	.4
2	106.54	[illegible]	106.34	105.14	105.24	115.34	[illegible]	104.74	104.64	[illegible]	[illegible]
3	80.14	78.94	80.34	76.74	77.84	78.64	77.84	76.64	70.64	[illegible]	1.41
4	43.44	43.74	43.94	44.34	43.34	42.64	42.24	43.64	43.14	43.38	[illegible]
5	14.80	14.80	15.20	15.00	14.70	14.15	14.80	14.40	14.60	14.71	[illegible]
6	[illegible]	8.89	8.89	8.57	7.94	8.26	8.21	7.94	7.62	[illegible]	[illegible]
7	[illegible]	29.84	33.02	30.48	31.43	31.43	30.89	30.83	31.12	31.12	.67
8	[illegible]	29.84	28.26	29.53	28.26	27.94	29.53	29.84	28.58	29.03	.76
9	[illegible]	12.06	11.75	11.75	12.70	10.16	11.11	12.70	12.06	11.92	.89
10	[illegible]	50.48	45.72	49.21	48.58	46.99	47.62	46.04	46.36	47.80	1.66
11	[illegible]	25.40	25.40	25.08	25.72	25.40	25.40	24.76	25.40	25.47	.32
12	[illegible]	48.26	48.26	48.58	48.64	49.85	48.94	48.26	48.26	48.62	.51
13	[illegible]	14.90	15.10	15.00	15.10	14.90	14.80	15.00	15.20	15.06	.21
14	[illegible]	47.00	47.40	47.60	46.90	47.40	47.50	48.60	48.30	47.54	.59
15	[illegible]	[illegible]	52.80	55.20	57.80	56.40	54.20	56.80	[illegible]	[illegible]	1.95
16	[illegible]	39.90	40.30	30.30	40.20	38.00	39.90	40.00	39.60	[illegible]	.71
17	[illegible]	39.00	37.70	37.00	41.70	36.10	37.10	37.90	37.80	37.40	2.49
18	28.70	36.40	35.60	34.40	37.10	33.00	35.70	37.80	35.80	34.94	2.73
19	61.91	61.80	61.91	60.01	60.01	62.23	60.96	59.37	61.60	61.07	1.93

2.3.4 Photogrammetric Calibration

Calibration of conversion constants was based upon the method illustrated in Figure 4 . The fiducials on the lexan panel ($y= -32.062$) and the side of the seat pan ($y= -8.0$) were digitized and the average conversion factors for those planes were calculated to be 2787.13 counts per foot (cpf) and 1650.74 cpf respectively.

Referring to Figure 4 the following values were assigned:

$$r_o = r_{02} = 1 \text{ foot}$$

$$r_p = 1650.74 \text{ counts}$$

$$r_{p2} = 2787.13 \text{ counts}$$

$$s_o - s_{02} = 24.062 \text{ inches.}$$

The distance, r, from the axis at which the ray from p_o to the focal point penetrated the object 2 plane was calculated to be:

$$\frac{r}{r_{02}} = \frac{rp}{r_{p2}}$$

$$r=1 \text{ foot} \times \left(\frac{1650.74 \text{ counts}}{2787.13 \text{ counts}}\right)$$

$$r = .592 \text{ foot} = 7.107 \text{ inches.}$$

The apparent distance from the focal point to the plane $y= -8.0$ inches was calculated to be:

$$\frac{s_o}{s_o-s_{o2}} = \frac{r_o}{r_{02}-r}$$

$$s_o = (s_o-s_{o2}) \left(\frac{r_o}{r_{02}-r}\right)$$

$$s_o = 24.062 \text{ inches} \left(\frac{12 \text{ inches}}{4.893 \text{ inches}}\right)$$

$$s_o = 59.01 \text{ inches.}$$

Calculation of a conversion constant, f_n, for any plane, y=n, was then accomplished using

$$f_n = \frac{s_o}{s_o + (8-y)} \times 1650.74 \text{ counts per foot}$$

when y=n=one half the measured breadth of the subject between anthropometric points on the left and right side.

2.3.5 Data Reduction Process

The data reduction process consisted of data editing, digitizing, and electronic data processing. Film editing and digitizing were accomplished on the Producers Service Corporation model PVR film analyzer (PVR) interfaced with a teletype terminal (TTY) with paper tape punch. Tape to card conversion and electronic processing and plotting were accomplished on the CDC Cyber 74 System at the Aeronautical Systems Division's Digital Computation Facility (ASD/AD) in Building 676, Area B, Wright-Patterson Air Force Base.

2.3.5.1 Editing

The primary camera film was viewed on a light table and the frames and .01 second timing pulses were counted throughout the event. The frame exposure rate (frames per second) was scanned for consistency and the average frame rate was calculated. During each run processed the frame rate was constant, ± 1 frame per second, during the 300 milliseconds following initiation. During the program film speeds ranged from 462 to 495 frames/second.

The film was mounted on the PVR and was transported forward in the cine mode until the operator observed that the subject motion had apparently terminated. The number of the frame was noted as termination time.

2.3.5.2 Digitizing

Upon completion of the editing procedure, the film was transported reverse to frame zero, the first frame in which the strobe flash was observed.

1. Seat forward fiducial
2. Seat aft fiducial
3. Hip fiducial
4. Knee fiducial
5. Shoulder fiducial
6. Elbow fiducial
7. Trageon fiducial
8. 9TAP mount fiducial

The digital values of these coordinates, preceeded by the frame number, were punched into paper tape in the format (I5, 8F7.0/I5, 8F7.0). Each of the 8F7.0 fields contained four pairs of coordinates.

After the coordinates projected from frame zero were digitized, the coordinates from each succeeding frame were digitized in the same sequence until frame 150 (approximately 300 msec).

2.3.5.3 Electronic Data Processing

This portion of the process required three procedures, data preparation, computation, and plotting.

Data Preparation: During the data preparation procedure, the file recorded on punched paper tape was communicated to the computer at ASD/AD from a TTY via voice quality lines. The file was then edited to correct format and/or character errors, and was batched to a card punch for creation of the permanent file. Concurrently, the identification, control, and conversion constant cards required by program HIFPD were punched for merger with the card file.

The identification card contained alphanumeric information in cards columns (cc) 1 thru 80 which was printed on output tables as table identification. The form used was RSD STUDY, SUBJECT--, RUN----, YYMMDD, material. The next to last entry is the date on which the test was conducted in terms of year, month, and day of month.

The control card contained the test number and program control switch characters. The format and definition of switching functions is listed in Paragraph 2.2.10.

The conversion constant card contained the film speed (frames per second) and conversion constants to be applied to the second, third, and fourth pairs of coordinates on the first line read from each frame, and the first thru fourth pairs of coordinates on the second line read from each frame. The format for this card was (8F10.0).

Upon receipt of the card file of PCS coordinate readings, it was merged with the previously punched ID, control, and constant cards, and the computer control cards for submission to ASD/AD for computation. The composition of a typical computer run deck is illustrated in Figure 14.

Computation: Film frame coordinate positions of the tracked points were converted to 2 dimensional seat coordinate time histories by program HIFPD.

The PCS coordinate readings of the two reference fiducials from the first film frame were used as the basis for the location of optical axis relative to the reference points and for the angular relationship between the axes of the PCS and the SCS. Readings of these points from each subsequent film frame translated and rotated the PCS coordinate system to coincide with the orientation of the first frame. This was done to minimize errors due to vibration of the camera during the test event.

The displacement from the second reference point was calculated by ... nates by the conversion constant ... from the optical axis of each of the tracked ... by dividing its PCS coordinates by its ... values of x and z displacements from the ... ference point was then subtracted from the ... of each of the tracked points yeilding x and z ... point relative to the reference point. ... calculated coordinate system had been translated ... of the aft seat reference fiducial.

From the time histories of ... positions, HIFPD computed total velocity ... histories of each point, fitting a moving ... points during each differentiation, and the ... acceleration time histories of the 9TAP mount ... and of the shoulder about the hip point; again ... quadratic arc to eleven points during each diff...

The resulting time histories were ... tables and written on magnetic tape for plotting.

Plotting: After examination of ... results of the computation revealed no apparent ... plot request was submitted to ASD/AD. The data ... magnetic tape by HIFPD were read and plotted ... COMP Plotter.

2.3.6 Results and Accuracy

The results of this effort were delivered ... tories of displacement, velocity and acceleration ... graphic forms.

Analysis of the propagation of error ... points resulted in a maximum estimated error ... points except the elbow.[2] During all test ... strated lateral motion toward the plane of symmetry ...

[2]Graf, P.A. and H.T. Mohlman, Accuracy ... Data, AMRL-TR-79-76, April, 1980, Aerospace ... Laboratory, Wright-Patterson Air Force Base, ...

extremities extended forward from the seat. These lateral excursions of the elbows caused the breadth across the elbows to approach, but not become less than, the bread n across the shoulders at maximum extension of the arms. The mean of the maximum lateral excursion of the elbows was 1.96 inches from a mean lateral displacement of 10.84 inches from the plane of symmetry to 8.88 inches. The estimated error in solutions to elbow coordinates at maximum extension of the arms was 0.23 inches.

From a study conducted by H. T. Mohlman of the UDRI, the effects of smoothing the raw solutions and the first and second derivatives may be summarized as follows:

(1) Attenuation of peak values of displacement, velocity and acceleration is a function of frequency.

(2) The eleven point quadratic fit yields closer correlation than either seven, nine, thirteen, or fifteen point quadratic fits.

(3) The attenuation of any specific displacement, velocity, or acceleration peak would be reasonably predictable if the frequency of the peak could be properly interpreted. A technique used to evaluate the frequency response characteristics of the smoothing filter is described in a later section (page 115) and is detailed in the above reference report.

(4) Oscillations in velocity and acceleration curves are predominatly artifacts induced in the smoothing fit.

The referenced work included investigation of sampling theory and application of the quadratic fits to digitized photometric data acquired during BPRD tests 172 and 173.

The accuracy of the digitizing was checked using the standard deviation about the mean for the solution of the rear seat reference point with respect to the forward reference point. The standard deviations were:

[illegible]	[illegible]-AXIS	[illegible]-AXIS
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	.0044	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	.0014	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

The largest standard deviation in the sample, 0.0044 feet, represents a standard deviation of [illegible] counts which is considerably less than the 10 count standard deviation used to estimate the error.

The effect of smoothing the displacement solutions of the tracked points are indicated in Table 11, which presents the standard deviations of the difference between unsmoothed and smoothed components of the displacements taken from a representative sample of the tests. The resultant standard deviations in the sample range from .029 inch (test 1340, hip) to 0.052 inch (test 993, head point 1), were considerably less than the estimated maximum error of 0.12 inch.

2.4 -50G$_x$ INJURY PROTECTION COMPARISON

Cadaver subjects have been widely used to assess patterns and severity of injury resulting from exposure to impact environments. These assessments have been used as the basis for predicting the probability of injury to living beings who might be subjected to similar environments. An investigation of the reliability of this approach to injury protection assessments was required to compare results between living subjects and cadavers.

TABLE 11

STANDARD DEVIATION OF DIFFERENCE BETWEEN UNSMOOTHED AND SMOOTHED DISPLACEMENT IN FEET

	TEST 1135		TEST 1137		TEST 1034	
	x-Axis	z-Axis	x-Axis	z-Axis	x-Axis	z-Axis
Hip	.0030	.0031	.0016	.0021	.0019	.0022
Knee	.0021	.0026	.0019	.0022	.0022	.0020
Shoulder	.0057	.0040	.0037	.0026	.0041	.0030
Elbow	.0032	.0039	.0027	.0025	.0030	.0026
Head Point 1	.0047	.0045	.0054	.0039	.0057	.0035
Head Point 2	.0054	.0044	.0057	.0027	.0060	.0045

	TEST 993		TEST 1046		TEST 1153	
Hip	.0020	.0026	.0016	.0015	.0015	.0021
Knee	.0028	.0026	.0018	.0020	.0024	.0021
Shoulder	.0050	.0032	.0027	.0024	.0034	.0025
Elbow	.0035	.0021	.0026	.0017	.0023	.0021
Head Point 1	.0061	.0047	.0042	.0038	.0047	.0036
Head Point 2	.0065	.0039	.0052	.0030	.0049	.0027

	TEST 1140		TEST 1142		TEST 1151	
Hip	.0017	.0017	.0017	.0018	.0017	.0018
Knee	.0016	.0021	.0019	.0021	.0019	.0017
Shoulder	.0036	.0023	.0029	.0026	.0034	.0024
Elbow	.0022	.0017	.0018	.0017	.0025	.0018
Head Point 1	.0055	.0038	.0039	.0030	.0042	.0036
Head Point 2	.0049	.0026	.0040	.0020	.0044	.0030

The Impact Protection Branch of the Aerospace Medical Research Laboratory (AMRL/BBP) conducted a test program to compare the responses of live anesthetized baboons with those of baboon cadavers. The intent was to match live animals with cadavers of similar anthropometry in pairs for comparative analysis. The data presented herein were derived from cinematographic recordings of the body segment responses of the subjects during -50 G_x simulations conducted on the AMRL/BBP Horizontal Impulse Accelerator Facility during December 1977 and the AMRL/BBP Hydraulic Decelerator Facility during May 1978. These facilities are both located at AMRL/BBP, Wright-Patterson Air Force Base, Ohio.

Eighteen tests were conducted on the Horizontal Impulse Accelerator Facility. Six tests were conducted using a scaled three-point harness, three (1444 thru 1447) involved live anesthetized subjects, and three (1449 thru 1451) involved cadavers. A camera malfunction during test 1446 resulted in loss of photo data from that test.

Six live anesthetized subjects (tests 1453, 1454, 1456, 1457, 1459 and 1460) and six cadavers (tests 1462, 1463, 1464, 1466, 1467, and 1468) were exposed to the impact environment while restrained with a military type harness. Photometric data from these twelve tests was good and was reduced.

During the -50 G_x simulations conducted on the Hydraulic Decelerator Facility in May 1979, six live anesthetized subjects (tests 103, 104, 105, 106, 108, and 109) and six cadavers (tests 110, 111, 113, 114, 115, and 116) were exposed while restrained with a military type harness. Because of a camera malfunction during test 110, photometric descriptions of the responses of only five cadavers were available for comparison.

2.4.1 Requirements

Primary requirements of the photometric data analysis effort were to derive, from cinematographic recordings, time histories of coordinate positions, velocities, and accelerations

[illegible], knee, shoulder, elbow and head. Angular velocity and acceleration of the head about its y axis were [illegible].

The points to be tracked were defined as follows:

Hip : The lateral-most point on the greater femoral trochanter.

Knee : The lateral-most point on the lateral femoral condyle.

Shoulder : The lateral-most point on the acromion process of the scapula.

Elbow : The lateral-most point on the lateral humeral condyle.

Head : The geometric center of the head accelerometer pack.

[illegible] : Tip of the snout.

The points defined above are accepted as standard anthropometric landmark points in accordance with SAE J138, SAE Handbook, 1975 with the exception of those on the head. Ideally, a point at approximately the center of gravity of the head would have been specified however prior experience dictated that the upper torso and head of each subject would require restraint from lateral movement during the countdown. The method of restraining the head and upper torso was to be such that it would have little or no effect on lateral responses. Again prior experience indicated the use of masking tape from one side of the headrest around the head under the mouth to the other side of the headrest would stabilize the lateral position of the subject. This method of restraining the head obscured the fiducial applied over the jaw hinge, thus the center of the accelerometer pack was specified.

2.4.2 Photometric Range

The photometric range, as illustrated in Figure 17, was a three dimensional, mutually perpendicular coordinate system. The origin was at the intersection of the seatpan plane, the seatback plane, and the plane of symmetry of the seat. The x-axis was positive forward along the horizontal line, the y-axis was

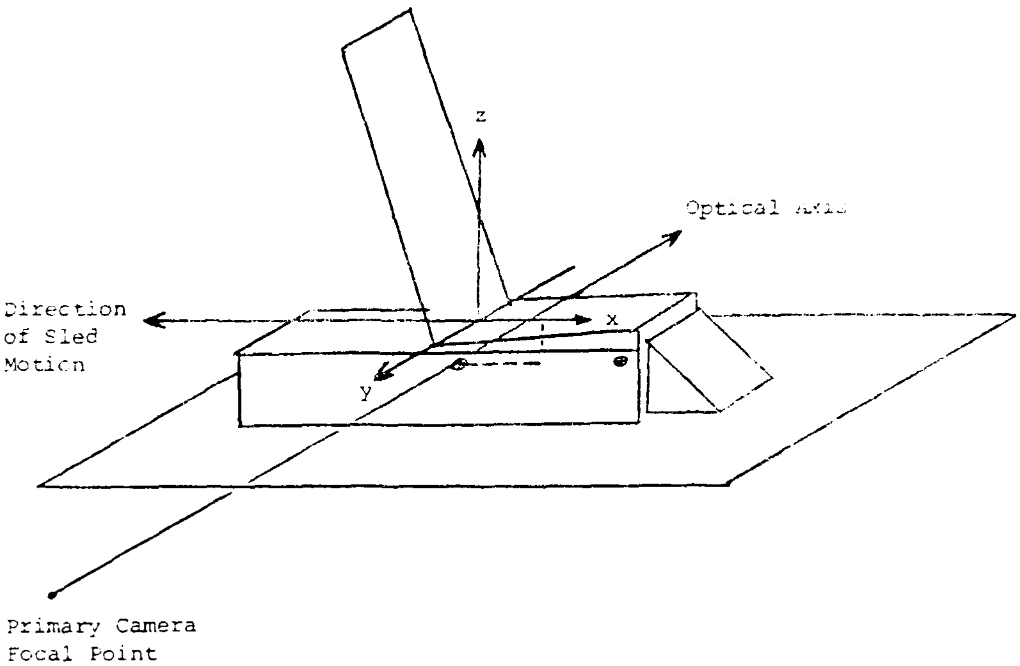


Figure 17. $-50\ G_x$ Injury Protection Comparison Photometric Range and Seat Coordinate System.

positive to the right of the seat along the horizontal line, and the z-axis was positive upward along the zenith line.

The Photosonics model 1B cameras, with 8mm lenses, were mounted onboard the sled. The primary data camera was mounted with its focal point at coordinates (11.84, 53.12, 3.88) inches. Its optical axis was normal to the plane of symmetry of the seat. The front view camera was mounted with its focal point at coordinates (63.65, 0.75, 4.0) inches. Its optical axis was parallel to the x axis.

Seat reference fiducials were applied to the RH side of the seat frame structure at coordinates (2.28, 5.88, -3.7) inches and (10.70, 5.88, -4.29) inches.

2.4.3 Photogrammetric Calibration

Review of films of the first tests demonstrated severe "barrel" distortion of the image (magnification decreased as distance from the optical axis increased). A grid board, made of flat black plywood with a 1-inch by 1-inch grid of white threads, was held with its face in the plane y=0 and was photographed on the primary data camera. The grid board was then held with its face in the plane x=.5 inch and was photographed on the front view camera.

The film image recorded on the primary data camera (side view) was mounted on the Producers Service Corporation model PVR film analyzer. The grid system was rotated until the horizontal grid line closest to the x-axis and the vertical grid line closest to the y-axis were parallel to the respective axis.

The intersections of the vertical grid line images and the x-axis were digitized from the line which coincided with the y-axis to the grid line 32 inches forward from it. This was replicated twice and the three sets of readings were averaged. The average readings were plotted versus grid board displacement (Figure 18). Since program HIFPD was used to process the data,

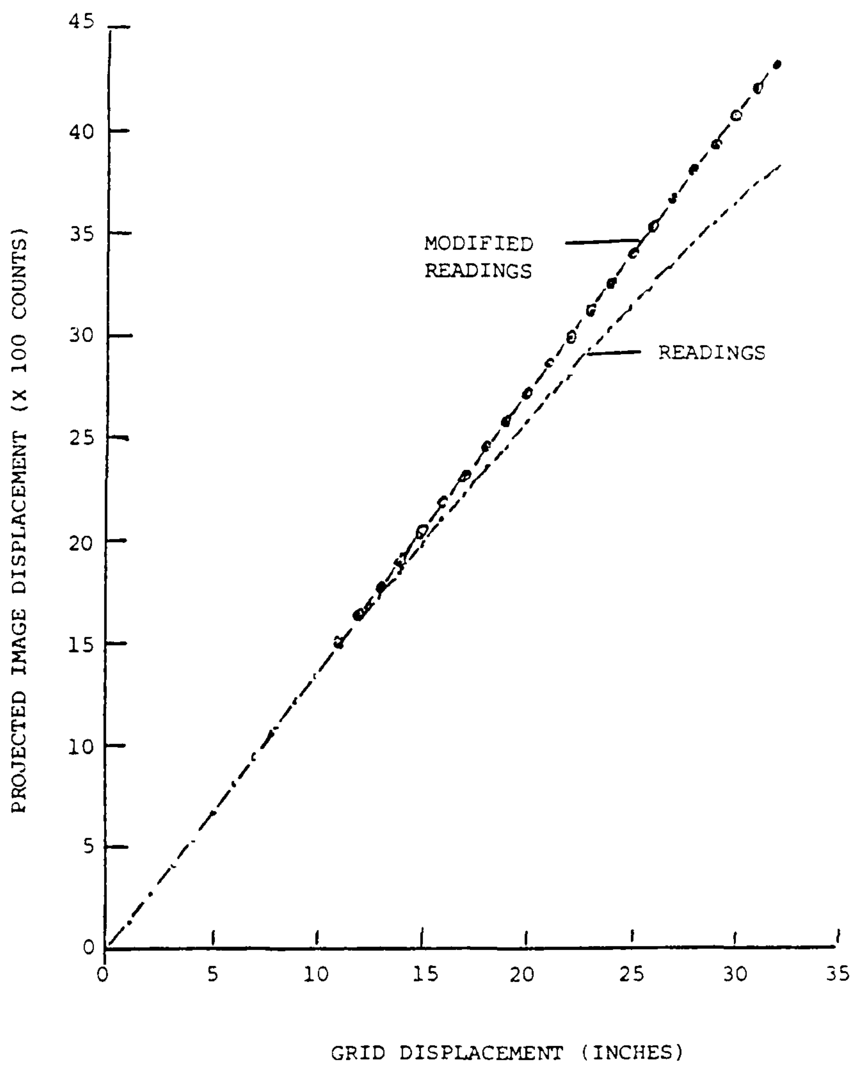


Figure 18. Average and Modified $-50G_X$ Readings Versus Grid Displacement.

it was incumbent that the readings be modified to present a linear relationship between observed point distance from the optical axis and corrected image distance from the optical axis.

As is the case with most fine wide angle lenses, the linear displacement of an image point from the optical axis approximated a direct relationship to angular displacement from the optical axis to the line from the focal point to the observed point.

From readings of grid lines in the relatively undistorted central portion of the image frame (cos $\theta \geq .99$) and the fiducials on the seat frame structure, the apparent distance from the focal point to the grid was calculated to be 60.63 inches by the method illustrated in Figure 4. Using an arc of radius 60.63 inches each reading was modified by dividing by the cosine of the angle between the optical axis and the ray from the observed point. A conversion factor was calculated in terms of counts read per inch grid displacement for each point. The best straight line fit to the resulting conversion factors was calculated to be 136.1 counts per inch (1633.2 counts per foot). The coefficient of determination (r^2) and correlation coefficient (r) each exceeded .9999. Application of this conversion constant to the modified readings resulted in solutions within $\pm$ .10 inch. These results are tabulated in Table 12 and plotted in Figure 18. The mean of the errors was .0206 inch and the standard deviation was .0345 inch.

2.4.4 Data Acquisition

Prior to the start of the test program range survey data, presented in the Photometric Range section, were measured and recorded.

During preparation for each data run, fiducials were marked on the anthropometric points to be tracked. These fiducials were applied with a black felt tip marker since no self-adhering fiducials had been found to effectively adhere to the skin of the subjects

TABLE 12

DATA FOR MODIFICATION OF FILM READING TO COMPENSATE FOR IMAGE DISTORTION

Grid Displacement (inches)	Average Image Displacement (counts)	Angular Displacement from Optical Axis (θ) (degrees)	Reading / cos θ	f (counts/inch)	Calculated Displacement (inches)
1	134.3	.9449	134.3	134.3	.98
2	272.7	1.889	272.8	136.4	[illegible]
3	407.5	2.833	408.0	136.0	3.[illegible]
4	541.6	3.775	542.8	135.7	3.99
5	[illegible]	4.714	[illegible]	136.6	[illegible]
6	813.5	5.652	817.0	136.2	[illegible]
7	947.5	6.586	953.8	136.3	7.[illegible]
8	1086.0	7.517	1095.4	136.9	8.05
9	1215.0	8.443	1228.3	136.5	[illegible]
10	1349.5	9.366	[illegible]	136.8	[illegible]
11	1478.7	10.283	[illegible]	136.6	11.[illegible]4
12	1603.3	11.135	1634.4	136.2	[illegible]
13	1737.0	12.102	1776.[illegible]	[illegible]	13.[illegible]
14	1857.0	13.002	1905.4	136.1	14.[illegible]
15	1986.7	13.896	2046.0	136.4	15.[illegible]4
16	2113.0	14.783	2185.3	136.6	16.05
17	2233.0	15.663	2319.1	136.4	17.[illegible]4
18	2360.0	16.535	2461.8	136.3	18.[illegible]
19	2472.3	17.400	2590.9	136.4	[illegible]
20	2588.0	18.256	2725.2	136.3	[illegible]
21	2709.0	19.104	2866.9	136.5	21.[illegible]
22	2812.3	[illegible].944	2991.7	136.0	22.[illegible]
23	2925.7	20.774	3129.1	136.0	22.[illegible]
24	3040.0	21.596	3269.5	136.2	24.[illegible]
25	3149.3	22.408	3406.5	136.0	25.[illegible]
26	3256.0	23.211	3542.6	136.1	[illegible]
27	3357.0	24.[illegible]	3674.6	136.1	[illegible]
28	3463.7	24.786	3815.2	136.3	28.[illegible]
29	3562.6	25.562	3949.2	136.2	[illegible]
30	3668.5	26.326	4093.[illegible]	136.4	[illegible]
31	3759.3	27.081	4222.[illegible]	[illegible]	[illegible]
32	3840.0	27.825	[illegible]	[illegible]	[illegible]

The anthropometric sitting height of the subject was measured while the subject was lying on its side. The measurement was taken from the lower base of the tail to the level of the brow ridge.

After the subject was positioned and the harness pretensioned, the lengths of the body segments and breadths at the shoulder, elbow, and knee fiducials were measured and recorded. The sitting height was again measured from the seat pan to the brow ridge along a line parallel to the seat back. These data along with subject and run signature data were recorded on a pretest measurements form. The data are defined in Table 13 and are presented in Tables 14 thru 16.

Cinematographic recordings of the subject were made on the cameras described in the Photometric Range section. The data cameras were operated at a nominal speed of five hundred (500) frames per second from time t= -2.0 to t= +2.0 seconds. Timing on the films was accomplished by a pulsed light emitting diode (LED) driven at 100 pulses per second. Synchronization was accomplished by a strobe flash triggered by a t=0 pulse simultaneously recorded on the electronic data acquisition system.

2.4.5 Data Reduction Process

The data reduction process consisted of data editing, digitizing, and electronic data processing. Film editing and digitizing were accomplished on the Producers Service Corporation model PVR film analyzer (PVR) interfaced with a teletype terminal (TTY) with paper tape punch. Tape-to-card conversion and electronic processing and plotting were accomplished on the CDC Cyber 74 system at the Aeronautical Systems Division's Digital Computation Facility (ASD/AD) in Building 676, Area B, Wright-Patterson Air Force Base, Ohio.

TABLE 13

PRETEST MEASUREMENTS

Data Item	Definition
1	Test Run Number.
2	Date of Test Run.
3	Subject Identification.
4	Weight of Subject (lbs).
5	Sitting Height (cm) measured from seat pan surface to brow ridge, parallel with seat back plane.
6	Distance (cm) in x-z plane between tip of snout and center of head accelerometer pack mounting screw.
7	Distance (cm) in x-z plane between center of head accelerometer pack mounting screw and jaw hinge point.
8	Distance (cm) in x-z plane between jaw hinge point and shoulder point.
9	Distance (cm) between the shoulder point and the hip point.
10	Distance (cm) between the shoulder point and elbow point.
11	Distance (cm) between hip point and knee point.
12, 13	Anthropometric sitting height (12 cm; 13 in). Measured from lower base of tail to brow ridge while subject lying on side.
14	Breadth (cm) across shoulder points.
15	Breadth (cm) across elbow points.
16	Breadth (cm) across knees.

TABLE 14A

[illegible] PRETEST MEASUREMENTS, LIVE SUBJECTS, [illegible] PT HARNESS, ACCELERAT[illegible]

Data Item			
1	1444	1446	1447
2	771206	[illegible]	[illegible]
3	F-14	[illegible]	F-12
4		50.5	46.[illegible]
5	63.4	65.[illegible]	65.4
6	[illegible]	[illegible]	[illegible]
7	[illegible].8	[illegible].8	[illegible]
8	[illegible]	[illegible]	18.7
9	[illegible]	14.[illegible]	14.[illegible]
10	20.7	[illegible].2	21.[illegible]
11	20.6	22.[illegible]	21.2
12		64.8	64.5
13		25.[illegible]	27.[illegible]
14	21.3	22.8	[illegible]
15	30.[illegible]	24.6	25.[illegible]
16	26.[illegible]	21.[illegible]	18.[illegible]

TABLE 14B

IPC PRETEST MEASUREMENTS, CADAVER SUBJECTS, [illegible] PT HARNESS, ACCELERAT[illegible]

Data Item			
1	1449	1450	1451
2	771208	771208	7712[illegible]8
3	F-10	F-06	[illegible]-02
4	[illegible]	48.[illegible]	54.[illegible]
5	64.8	63.7	65.[illegible]
6	7.8	8.[illegible]	[illegible]
7	4.7	[illegible]	[illegible]
8	16.2	[illegible]	19.[illegible]
9	36.[illegible]	[illegible]	34.3
10	19.[illegible]	19.[illegible]	14.3
11	21.3	[illegible]	[illegible]
12	[illegible]	63.[illegible]	66.[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

TABLE [illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]				
	[illegible]	[illegible]			[illegible]	[illegible]
[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	28.	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE [illegible]5B

[illegible] PRETEST MEASUREMENTS, [illegible]

[illegible]

[illegible]	[illegible]	.46[illegible]	.464	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	46.	45.[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	25.	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 16A

IPC PRETEST MEASUREMENTS LIVE SUBJECTS MIL HARNESS, DECELERATOR

Data Item						
1	103	104	105	106	108	109
2	780503	780503	780503	780503	780504	780504
3	F68	F78	F76	F86	F66	F64
4	50.0	51.0	51.5	47.25	57.5	50.5
5	66.4	70.5	68.7	66.6	69.9	66.6
6	8.9	7.4	7.8	7.9	7.7	10.2
7	9.7	11.1	10.9	8.8	10.7	9.7
8	16.5	14.1	14.8	17.2	18.4	15.2
9	39.1	40.0	40.0	37.9	39.4	39.0
10	22.4	23.2	24.1	23.1	20.6	23.0
11	27.9	26.9	26.8	22.0	21.5	25.6
12	71.1	67.9	68.6	64.8	67.3	70.5
13	28.0	26.75	27.0	25.5	26.5	27.75
14	22.4	20.2	21.2	19.2	21.4	22.1
15	22.9	23.1	28.0	26.1	27.2	29.0
16	20.5	9.0	21.3	25.7	26.1	15.1

TABLE 16B

IPC PRETEST MEASUREMENTS CADAVER SUBJECTS MIL HARNESS, DECELERATOR

1	110	111	113	114	115	116
2	780504	780504	780505	780505	780505	780505
3	F82	F84	F80	F72	F70	F74
4	45.75	53.5	51.25	48.0	46.0	56.0
5	64.0	70.0	67.0	71.8	67.4	70.5
6	9.0	8.0	8.1	6.5	9.0	8.9
7	8.7	10.1	8.6	7.5	8.5	9.4
8	13.5	14.3	[illegible]	16.0	17.8	14.3
9	38.9	43.7	40.3	43.0	39.5	42.1
10	21.6	22.7	20.0	28.0	23.3	23.0
11	24.0	26.5	20.6	23.2	26.0	21.3
12	64.8	67.3	63.5	70.5	69.8	69.2
13	25.5	26.5	25.0	27.75	27.5	27.25
14	21.0	19.5	20.6	21.3	21.7	21.8
15	24.6	30.3	32.7	24.2	25.7	25.5
16	19.5	23.0	14.0	19.8	17.2	27.0

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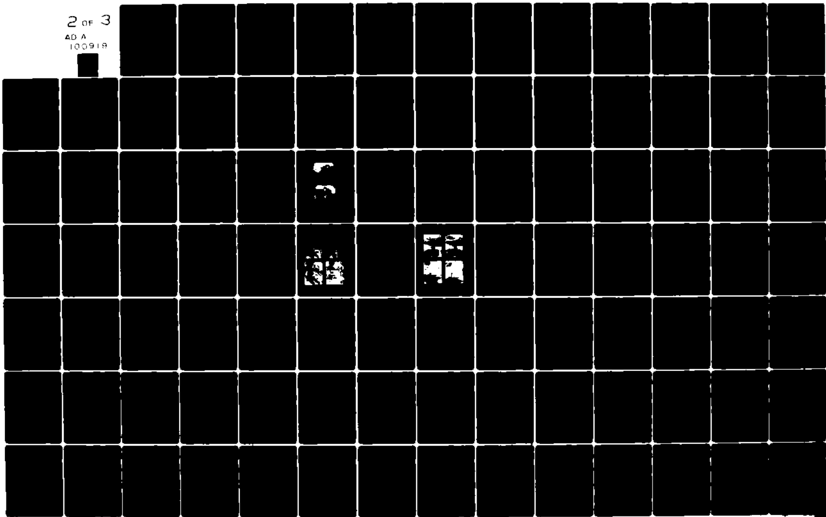


2.4.5.1 Editing

The seat side view camera film was viewed on a light table and the frames and 0.01 second timing pulses were counted throughout the event. The frame exposure rate (frames per second) was scanned for consistency and the average frame rate was calculated. During the test program the film speed ranged between 485 and 515 frames per second. During each test run the film speed was constant ± 1 frame per second, during the 200 milli-seconds following initiation.

2.4.5.2 Digitizing

The film was mounted on the PVR and was trans-ported forward in the cine mode to frame zero, the first frame in which the strobe flash was observed. The scales on the PVR were translated and rotated until the coordinates of the seat forward and aft fiducials were read to be within ± 20 counts of (-150, -1370) and (-1310, -1300) respectively. The projected image coordinates were then digitized in the following sequence.

1. Seat forward fiducial
2. Seat aft fiducial
3. Hip fiducial
4. Knee fiducial
5. Shoulder fiducial
6. Elbow fiducial
7. Head accelerometer pack
8. Tip of snout

The digital values of these coordinates, pre-ceeded by the frame number, were punched into paper tape in the format (I5, 8F7.0/I5, 8F7.0). Each of the 8F7.0 fields contained four pairs of coordinates.

After the coordinates projected from frame zero were digitized, the coordinates from each succeeding frame were digitized in the same sequence until the frame in which either of the head point images was obscured by the arm image.

2.4.5.3 Electronic Data Processing

This portion of the process required three procedures, data preparation, computation, and plotting.

Data Preparation: During the data preparation procedure, the file recorded on punched paper tape was communicated to the computer at ASD/AD from a TTY via voice quality lines. The file was then edited to correct format and/or character errors. Program CHIFPD was then attached to modify the readings to compensate for distortion. CHIFPD (Appendix D) calculated the resultant distance from the origin of each pair of PCS coordinates read in by

$$r = \sqrt{x^2 + y^2}$$

The angle (γ) between the ray from the point and the optical axis was then calculated by

$$\gamma = \frac{r}{K}$$

where K was input as 138.7 counts/degree.

The modified abscissa (x_c) was determined by

$$x_c = \frac{x}{\cos\gamma} ,$$

and the modified ordinate (y_c) was calculated by

$$Y_c = \frac{y}{\cos\gamma}$$

The output was batched to a printer and a card punch for creation of the permanent file. Concurrently, the identification, control, and conversion constant cards required by program HIFPD were punched for merger with the card file.

The identification card contained alphanumeric information in card columns (cc) 1 through 80 which was printed on output tables as table identification. The form used was IPC TEST ---, IMPULSE ACCELERATOR (DECELERATOR).

The control card contained the test number and program control switch characters. The format and definition of switching functions is listed under "Description of Program HIFPD Input Data and Parameter Codes."

The conversion constant card contained the film speed (frames per second) and conversion constants to be applied to the second, third and fourth pairs of coordinates on the first line read from each frame, and the first through fourth pairs of coordinates on the second line read from each frame. The format for this card was (8F10.0).

Upon receipt of the card file of modified PCS coordinate readings, it was merged with the previously punched ID, control and constant cards, and the computer control cards for submission, to ASD/AD for computation. The composition of a typical computer runs deck is illustrated in Figure 14.

Computation: Film frame coordinate positions of the tracked points were converted to two-dimensional seat coordinate time histories by program HIFPD.

The PCS coordinate readings of the two reference fiducials from the first film frame are used as the basis for the location of optical axis relative to the reference points and for the angular relationship between the axes of the PSC and the SCS. Readings of these points from each subsequent film frame translated and rotated the PCS coordinate system to coincide with the orientation of the first frame. This was done to minimize errors due to vibration of the camera during the test event and to compensate for frame to frame variations caused by the rotating prism.

The displacement from the optical axis of the second reference point was calculated by dividing the PCS coordinates by the conversion constant contained in columns 11 through 20 in the conversion constant card. In turn the displacement from the optical axis of each of the tracked points was calculated by dividing its PCS coordinates by its conversion constant. The values of x and z displacements from the optical axis of each point were then subtracted from the x and z coordinates of the reference point yielding x and z coordinates of each point relative to the reference point. Thus the origin of the calculated coordinate system had been translated to the location of the aft seat reference fiducial.

From the time histories of seat coordinate positions, HIFPD computed total velocity and acceleration time histories of each point, fitting a moving quadratic arc to eleven points during each differentiation, and the angular velocity and acceleration time histories of the head accelerometer about the snout, and of the shoulder about the hip point, again fitting a moving quadratic arc to eleven points during each differentiation.

The resulting time histories were printed in tables and written on magnetic tape for plotting.

Plotting: After examination of the tabulated results of the computation revealed no apparent gross errors, a plot request was submitted to ASD/AD. The data written on the magnetic tape by HIFPD were read and plotted offline on the CAL-COMP Plotter.

2.4.6 Results and Accuracy

The results of this effort were presented in tabular and graphic forms.

In the data report deficiencies in the derivations of velocity and acceleration time histories were cited. These deficiencies and a brief description of the analyses upon which they were based were presented in Paragraph 2.3.6.

The accuracy of the digitizing was indicated by the standard deviation about the mean for the solution of the rear seat reference point with respect to the forward reference point. The standard deviations were:

Run	x-Axis (feet)	z-Axis (feet)
1444	.0035	.0002
1447	.0035	.0002
1450	.0017	.0001
1451	.0108	.0005
1453	.0021	.0001
1456	.0036	.0002
1462	.0027	.0001
1466	.0019	.0001
105	.0036	.0002
109	.0053	.0002
111	.0046	.0002
115	.0030	.0001

The effect of smoothing the displacement solutions of the tracked points are indicated in Table 17, which presents the standard deviations of the difference between unsmoothed and smoothed components of the displacements taken from a representative sample of the tests.

2.5 UPPER TORSO RETRACTION

The survivability of emergency escape from aircraft has historically been a primary concern of the United States Air Force. Over the years, as aircraft performance has been improved, the risk of injury, either fatal or disabling, has tended to increase. Research efforts leading to the development of devices and systems to provide improved injury protection and reduction of risk, and evaluation of the products of these efforts, have continuously been conducted and/or sponsored by the Air Force.

TABLE 17A

STANDARD DEVIATION OF DIFFERENCE BETWEEN UNSMOOTHED AND SMOOTHED DISPLACEMENT DATA IN FEET THREE POINT RESTRAINT, LIVE SUBJECTS

	TEST 1444		TEST 1447	
	x-axis	z-axis	x-axis	z-axis
Hip	.0032	.0017	.0063	.0049
Knee	.0025	.0032	.0085	.0061
Shoulder	.0037	.0031	.0137	.0129
Elbow	.0031	.0099	.0072	.0112
Head Point 1	.0135	.0086	.0110	.0075
Head Point 2	.0081	.0064	.0132	.0166

TABLE 17B

STANDARD DEVIATION OF DIFFERENCE BETWEEN UNSMOOTHED AND SMOOTHED DISPLACEMENT DATA IN FEET THREE POINT RESTRAINT, CADAVER SUBJECTS

	TEST 1450		TEST 1451	
	x-axis	z-axis	x-axis	z-axis
Hip	.0018	.0017	.0105	.0041
Knee	.0033	.0028	.0104	.0069
Shoulder	.0095	.0096	.0169	.0103
Elbow	.0083	.0042	.0147	.0112
Head Point 1	.0092	.0101	.0223	.0109
Head Point 2	.0163	.0107	.0252	.0137

TABLE 17C

STANDARD DEVIATION OF DIFFERENCE BETWEEN UNSMOOTHED AND SMOOTHED DISPLACEMENT DATA IN FEET MILITARY RESTRAINT, LIVE SUBJECTS

	TEST 1453		TEST 1456	
	x-axis	z-axis	x-axis	z-axis
Hip	.0023	.0024	.0031	.0034
Knee	.0056	.0050	.0038	.0039
Shoulder	.0140	.0049	.0104	.0052
Elbow	.0100	.0052	.0034	.0033
Head Point 1	.0083	.0062	.0101	.0089
Head Point 2	.0139	.0081	.0153	.0195

TABLE 17D

STANDARD DEVIATION OF DIFFERENCE BETWEEN UNSMOOTHED AND SMOOTHED DISPLACEMENT IN FEET MILITARY RESTRAINT, CADAVER SUBJECTS

	TEST 1462		TEST 1466	
	x-axis	z-axis	x-axis	z-axis
Hip	.0027	.0021	.0029	.0028
Knee	.0034	.0022	.0032	.0040
Shoulder	.0063	.0026	.0153	.0084
Elbow	.0039	.0033	.0067	.0069
Head Point 1	.0081	.0032	.0099	.0066
Head Point 2	.0078	.0024	.0093	.0048

TABLE 17E

STANDARD DEVIATION OF DIFFERENCE BETWEEN UNSMOOTHED AND SMOOTHED DISPLACEMENT DATA IN FEET

	TEST 105		TEST 109		TEST 111		TEST 115	
	x-axis	z-axis	x-axis	z-axis	x-axis	z-axis	x-axis	z-axis
Hip	.0036	.0038	.0035	.0032	.0036	.0036	.0040	.0024
Knee	.0074	.0055	.0040	.0044	.0034	.0036	.0042	.0033
Shoulder	.0077	.0055	.0081	.0031	.0154	.0057	.0069	.0030
Elbow	.0133	.0083	.0049	.0038	.0050	.0033	.0051	.0033
Head Point 1	.0104	.0074	.0196	.0120	.0138	.0073	.0093	.0109
Head Point 2	.0102	.0082	.0124	.0120	.0113	.0087	.0142	.0069

In an ejection environment, emphasis must be placed on the method of positioning and restraining the torso, head, and extremities of the crewman in his seat. Ideally the crewman would be restrained in such a manner that during an ejection event, he would demonstrate no motion relative to the seat. A crewman, however, also requires freedom of movement to perform his tasks. The obvious solution was the development of a restraint system which would provide the required freedom of movement but which in an emergency situation would rapidly retract the crewman into position and restrain him with force sufficient to protect him from responding adversely to the acceleration of the seat and the force of windblast.

The work described herein was accomplished to demonstrate a photo analysis method proposed for use to describe the response motion of body segments of human subjects exposed to the upper torso retraction environment. Laboratory simulations were conducted by the Biomechanical Protection Branch of the AF Aerospace Medical Research Laboratory (AMRL/BBP) during the period January - May 1978. The tests were conducted on the Body Positioning Restraint Device (BPRD) located in Building 824, Wright-Patterson Air Force Base, Ohio.

2.5.1 Requirements

Primary objectives of the photometric effort were:

(1) To describe position-time histories of anthropometric points defining the body segments relative to the test device seat, and to derive velocity and acceleration time histories of these points.

(2) To derive time histories of angular velocity and angular acceleration of the head about its y axis.

(3) To derive time histories of angular velocity and angular acceleration of the helmet about its y axis.

(4) To describe the position-time history of the retraction piston and to derive time histories of its velocity and acceleration.

Secondary objectives of this effort were:

(1) To record motion of the shoulder harness relative to the subject's sternum for the purpose of assessing slippage of the harness relative to the chest and shoulders.

(2) To record the test event from a number of viewpoints sufficient to demonstrate restraint system and subject performance.

The body segment motions specified for description were the upper arm, the upper leg, the torso and the head. The points selected to define these segments were:

upper arm: The lateral-most projection of the acromion process of the scapula and the lateral most point on the lateral humeral condyle.

upper leg: The lateral-most point on the greater femoral trochanter and the lateral most point on the lateral femoral condyle.

torso : The lateral-most point on the greater femoral trochanter and the spinous process of the seventh cervical vertebra (C-7), which overlies the first thoracic vertebra (T-1) when the head is erect.

head : The point located on the sagittal plane of the nose at the level of the pupils (which is the rhinion).

It was the concensus that in addition to the above, the lower leg and lower arm should also be defined although definition of these segments was not a current requirement. The former was defined by the lateral projection of the lateral malleolus of the

fibula, and the latter was defined by the lateral-most point on the lateral humeral condyle and the stylion.

Selection of all the above points was influenced by two primary concerns:

(1) The requirement that the points could repeatedly be located.

(2) The requirement that the points, or fixtures identifying the points, be observable throughout the test event.

All of the points described above are widely accepted as recommended points for defining body segments with the exception of the points on the head. The points on the head were selected because the helmet, together with the cupped chin strap, left only the forward facial area exposed. The points on the nose were considered to be the only practical points on the head which would satisfy the above requirements.

2.5.2 Photometric Range

The photometric range as illustrated in Figure 19, was a three dimensional, perpendicular coordinate system, the origin of which was at the intercept of the seatback plane, the seatpan plane, and the plane of symmetry of the seat. The z axis was positive upward along the centerline of the seatback, the x axis was positive forward along the line normal to the seatback plane, and y was positive to the right of the seat.

Reference fiducials were affixed to the seat structure, ten on the RH side panel and nine on forward facing surfaces. Three additional fiducials (20, 21, 22) were applied to the outboard surface of the RH side of the test facility frame structure forward of the seat. The points are identified in Figure 19 and their coordinate positions are presented in Table 18.

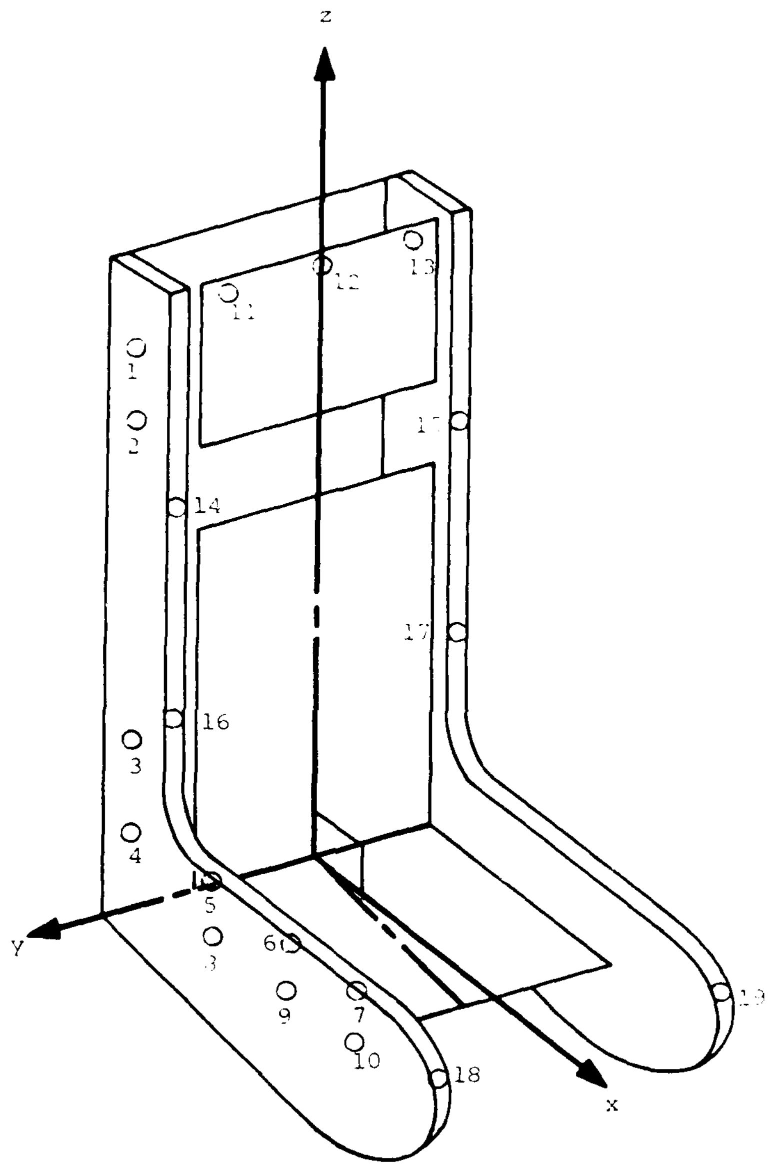


Figure 19. BPRD Seat Coordinate System and Reference Fiducial Locations.

TABLE 18

BPRD REFERENCE FIDUCIAL COORDINATES

Point	x(inches)	y(inches)	z(inches)
1	-2.05	10.5	34.57
2	-2.05	10.5	28.5
3	-2.05	10.5	10.55
4	-2.05	10.5	4.57
5	4.88	10.5	1.1
6	10.75	10.5	.43
7	15.87	10.5	- .25
8	4.41	10.5	- .83
9	10.35	10.5	- 1.26
10	15.55	10.5	- 1.69
11	0.0	7.68	40.28
12	0.0	0.0	40.30
13	0.0	- 7.83	40.31
14	0.0	9.83	22.64
15	0.0	9.83	22.64
16	0.0	- 9.83	12.6
17	0.0	- 9.83	12.6
18	22.89	9.83	- 3.16
19	22.88	- 9.83	- 3.24
20	32.45	-18.25	5.83
21	38.68	-18.25	2.08
22	31.24	-18.25	-12.27

Three Milliken 16mm motion picture cameras were mounted, two to the RH side of the test facility frame and the third forward of the frame. The locations of these cameras are illustrated in Figure 20 and the coordinates of their focal points and camera body orientations are listed in Table 19.

2.5.3 Photogrammetric Calibration

In the discussion of the approach to the photometric system two assumptions were made: that the focal lengths of the recording and projection lenses introduced no distortion, and that the focal lengths were precisely stated. The validity of these assumptions must be questioned.

A flat-black board, 24 inches x 48 inches, containing a 1 inch x 1 inch grid pattern of white thread was photographed by each camera as follows:

Camera	View	Board Location and Orientation
A	1	Surface in plane, y=0, longer edge on z axis, shorter edge on x axis.
A	2	Surface in plane, y= -6.97 inches, longer edge against plane x=0, shorter edge in plane z=0.
B	1	Surface in plane y=0, lower edge parallel with deck, 3/8 inch above deck. Longer edge against forward edge of seat pan.
C	1	Surface perpendicular to deck 1/2 inch forward of forward most points on armrests. Lower edge on deck.

These views of gridboard are on the film reel immediately after the views of test run 271.

From these films a slight "barrel distortion" was observed on all views. No corrections were made since the distortion was considered to be inconsequential in the area of the frame being evaluated.

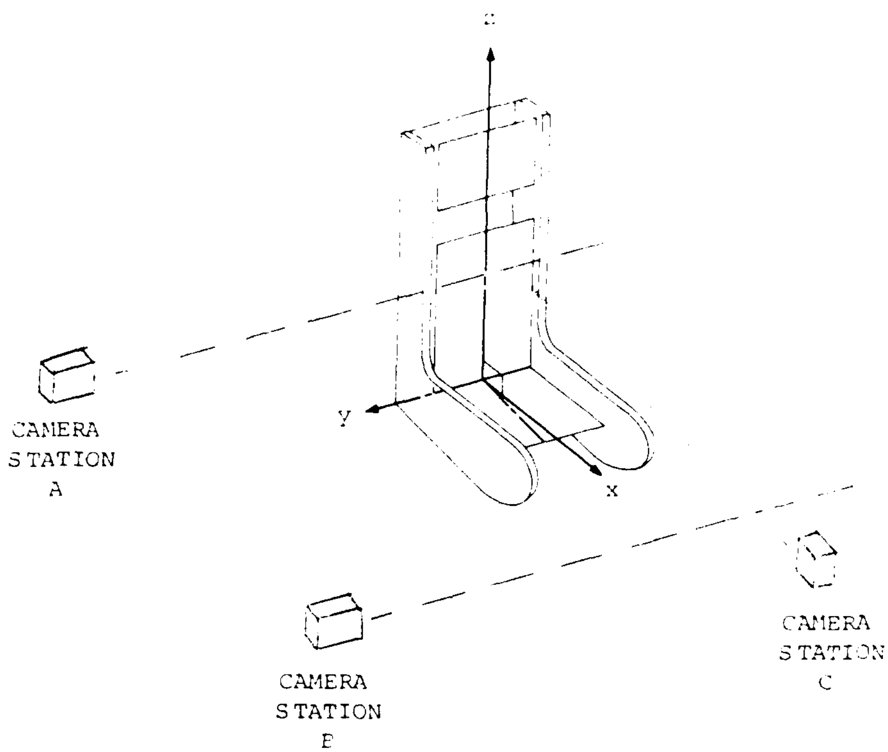


Figure 20. Camera Locations in BPRD Seat Coordinate System.

TABLE 19

BPRD COORDINATES OF CAMERA FOCAL POINTS
AND CAMERA BODY ORIENTATIONS

Camera Station	FOCAL POINT COORDINATES x(inches)	y(inches)	z(inches)	AZIMUTH (radians)	ELEVATION (radians)	ROLL (radians)
A	0.0	66.61	19.21	4.712	.006	.002
B	28.0	37.49	-6.72	4.712	-.002	.236
C	68.98	0.84	8.36	3.142	.299	.001

From the gridboard views recorded on the camera at Station A, readings were taken from the PCS z axis intercepts of five pairs of horizontal gridlines, the lines of each pair being twelve inches apart. This same procedure was applied to the PCS x axis intercepts of five pairs of vertical gridlines. An average of the displacements of the PCS readings was taken for each of the gridboard locations. The resulting conversion factors were 1377.75 counts per foot at SCS y=0 and 1548 counts per foot at SCS y= -6.969 inches.

Referring to Figure 4 the following values were assigned:

$$r_o = r_{o2} = 12 \text{ inches}$$

$$r_p = 1377.75 \text{ counts}$$

$$r_{p2} = 1548 \text{ counts}$$

$$s_o - s_{o2} = 6.97 \text{ inches.}$$

The distance from the axis at which the ray from p_o to the focal point penetrated the Object 2 Plane was calculated to be:

$$\frac{r}{r_{o2}} = \frac{r}{r_{p2}}$$

$$r = r_{o2} \; \frac{r_p}{r_{p2}}$$

$$r = 12 \text{ inches } \left(\frac{1377.75 \text{ counts}}{1548 \text{ counts}}\right)$$

$$r = 10.68 \text{ inches.}$$

The apparent distance from the focal point to the plane y=0 was calculated to be:

$$\frac{s_o}{s_o - s_{o2}} = \frac{r_o}{r_{o2} - r}$$

$$s_o = \left(s_o - s_{o2}\right) \; \frac{r_o}{r_{o2} - r}$$

$$s_o = 6.97 \text{ inches } \left(\frac{12 \text{ inches}}{1.32 \text{ inches}}\right)$$

$$s_o = 63.36 \text{ inches.}$$

Calculation of a conversion constant, f_n, for any plane, y=n, was then accomplished using:

$$f_n = \frac{s_o}{s_o - y} \times 1377.75 \text{ counts per foot}$$

where y was either one half the measured breadth of the subject between anthropometric points on the right and left side or the measured y displacement of fiducials on the test facility.

2.5.4 Data Reduction Process

The data reduction process consisted of data editing, digitizing, and electronic data processing. Film editing and digitizing were accomplished on the Producers Service Corporation model PVR film analyzer (PVR) interfaced with a teletype terminal (TTY) with paper tape punch. Tape to card conversion and electronic processing and plotting were accomplished on the CDC Cyber 74 System at the Aeronautical Systems Division's Digital Computation Facility (ASD/AD) in Building 676, Area B, Wright-Patterson Air Force Base.

2.5.4.1 Editing

The seat side view camera film was viewed on a light table and the frames and .01 second timing pulses were counted throughout the event. The frame exposure rate (frames per second) was scanned for consistency and the average frame rate was calculated. During the runs processed the frame rate was 500 ± 1 frames per second during the 300 milliseconds following initiation.

The film was mounted on the PVR and was transported forward in the cine mode until the operator observed that the subject motion had apparently terminated. The number of the frame was noted as termination time.

2.5.4.2 Digitizing

Upon completion of the editing procedure, the film was transported reverse to frame zero, the first frame in which the strobe flash was observed. The scales on the PVR were translated and rotated until the coordinates of fiducials 10 and 8 were read to be within ±20 counts of (2145, -2860) and (640, -2765) respectively. The projected image coordinates were then digitized in the following sequence.

1. Arm rest forward fiducial (10)
2. Arm rest aft fiducial (8)
3. Mid thigh fiducial
4. Knee fiducial
5. Shoulder fiducial
6. Elbow fiducial
7. Upper nose fiducial
8. Lower nose fiducial
9. Retraction piston fiducial
10. T-1 vertebra fiducial
11. Upper helmet fiducial
12. Lower helmet fiducial

The digital values of these coordinates, preceeded by the frame number, were punched into paper tape in the format (I5, 8F7.0/15, 8F7.0/15, 8F7.0). Each of the 8F7.0 fields contained four pairs of coordinates.

After the coordinates projected from frame zero were digitized, the coordinates from each succeeding frame were digitized in the same sequence until the fifteenth frame following the frame noted as termination time. The last fifteen frames were digitized to prevent timewise truncation of velocity

and acceleration curves due to smoothing of the data during electronic data processing.

2.5.4.3 Electronic Data Processing

This portion of the process required three procedures, data preparation, computation, and plotting.

Data Preparation: During the data preparation procedure, the file recorded on punched paper tape was communicated to the computer at ASD/AD from a TTY 35 via voice quality lines. The file was then edited to correct format and/or character errors, and was batched to a card punch for creation of the permanent file. Concurrently, the identification, control, and conversion constant cards required by program HIFPD were punched for merger with the card file.

The identification card contained alphanumeric information in card columns (cc) 1 thru 80 which was printed on output tables as table identification. The form used was RAPID RESTRAINT TEST _ _ _, SUBJECT __, YYMMDD. The last entry is the date on which the test was conducted in terms of year, month, and day of month.

The control card contained the test number and program control switch characters. The format and definition of switching functions is listed under "Description of Program HIFPD Input Data and Parameter Codes."

The conversion constant card contained the film speed (frames per second) and conversion constants to be applied to the second, third, and fourth pairs of coordinates on the first line read from each frame, and the first thru fourth pairs of coordinates on the second line read from each frame. The format for this card was (8F10.0).

Upon receipt of the card file of PCS coordinate readings, it was merged with the previously punched ID, control, and constant cards, and the computer control cards for submission to ASD/AD for computation. The composition of a typical computer run deck is illustrated in Figure 14.

Computation: Film frame coordinate positions of the tracked points were converted to two-dimensional seat coordinate time histories by program HIFPD, which is described fully in Section 2.2. Two versions of the program were filed. The first read the digitized values from the first and second lines from each frame and wrote the appropriate heading and labels on tables and plots. The second version read the digitized values in the first and third lines from each frame and wrote the appropriate headings and labels on tables and plots. This variation required two passes through the computer.

Although program HIFPD is documented herein a brief discussion of the application is warranted.

The PCS coordinate readings of the two reference fiducials from the first film frame are used as the basis for the location of optical axis relative to the reference points and for the angular relationship between the axes of the PCS and the SCS. Readings of these points from each subsequent film frame translated and rotated the PCS, coordinate system to coincide with the orientation of the first frame. This was done to minimize errors due to vibration of the camera during the test event.

The displacement from the optical axis of the second reference point was calculated by dividing the PCS coordinates by the conversion constant contained in columns 11 thru 20 in the conversion constant card. In turn the displacement from the optical axis of each of the tracked points was calculated by dividing its PCS coordinates by its conversion constant. The

values of x and z displacements from the optical axis of each point were then subtracted from the x and z displacements of the reference point yielding x and z coordinates of each point relative to the reference point. Thus the origin of the calculated coordinate system had been translated to the location of reference fiducial 8.

From the time histories of seat coordinate positions, HIFPD computed total velcoity and acceleration time histories of each point, fitting a moving quadratic arc to eleven points during each differentiation, and the angular velocity and acceleration time histories of the upper nose point about the lower, and of the shoulder about the mid thigh point; again fitting a moving quadratic arc to eleven points during each differentiation.

The resulting time histories were printed in tables and written on magnetic tape for plotting.

Plotting: After examination of the tabular results of the computation revealed no apparent gross errors, a plot request was submitted to ASD/AD. The data written on the magnetic tape by HIFPD were read and plotted offline on the CALCOMP Plotter.

2.5.5 Results and Accuracy

The results of this effort were presented in tabular and graphic forms. The accuracy with which these results represent the actual motions of the observed points is the subject of debate. The following deficiencies may be inferred from a study conducted by H. T. Mohlman of the UDRI.[1]

(1) **Attenuation of peak values of displacement, velocity** and acceleration is a function of frequency.

(2) The eleven point quadratic fit yields closer correlation than either seven, nine, thirteen, or fifteen point quadratic fits.

[1] Graf, P.A. and H.T. Mohlman, Accuracy of Digitized Photometric Data, AMRL-TR-79-76, April, 1980, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.

(3) The attenuation of any specific displacement, velocity, or acceleration peak is reasonably predictable if the apparent frequency of the peak is properly interpreted.

(4) Oscillations in velocity and acceleration curves are predominantly artifacts induced by reading errors. The frequency is a function of the sampling rate and the number of points included in the smoothing fit.

The referenced work included investigation of sampling theory and application of the quadratic fits to digitized photometric data acquired during BPRD tests 172 and 173.

Frequency response curves presented in Figure 21 were derived from fitting eleven points of sinusoidal motion at frequencies from 2 Hz to 35 Hz at a sampling rate of 500 samples/second. The data from which these curves were constructed are presented in Table 20 and are described in detail in the referenced report.

The accuracy of the digitizing was indicated by the standard deviation about the mean for the solution of the forward seat reference point with respect to the rear reference point. The standard deviations were:

Run	x-Axis (feet)	z-Axis (feet)
172	.0073	.00049
173	.0030	.00017

The effect of smoothing the displacement solutions of the tracked points are indicated in Table 21, which presents the standard deviations of difference between unsmoothed and smoothed components of the displacements.

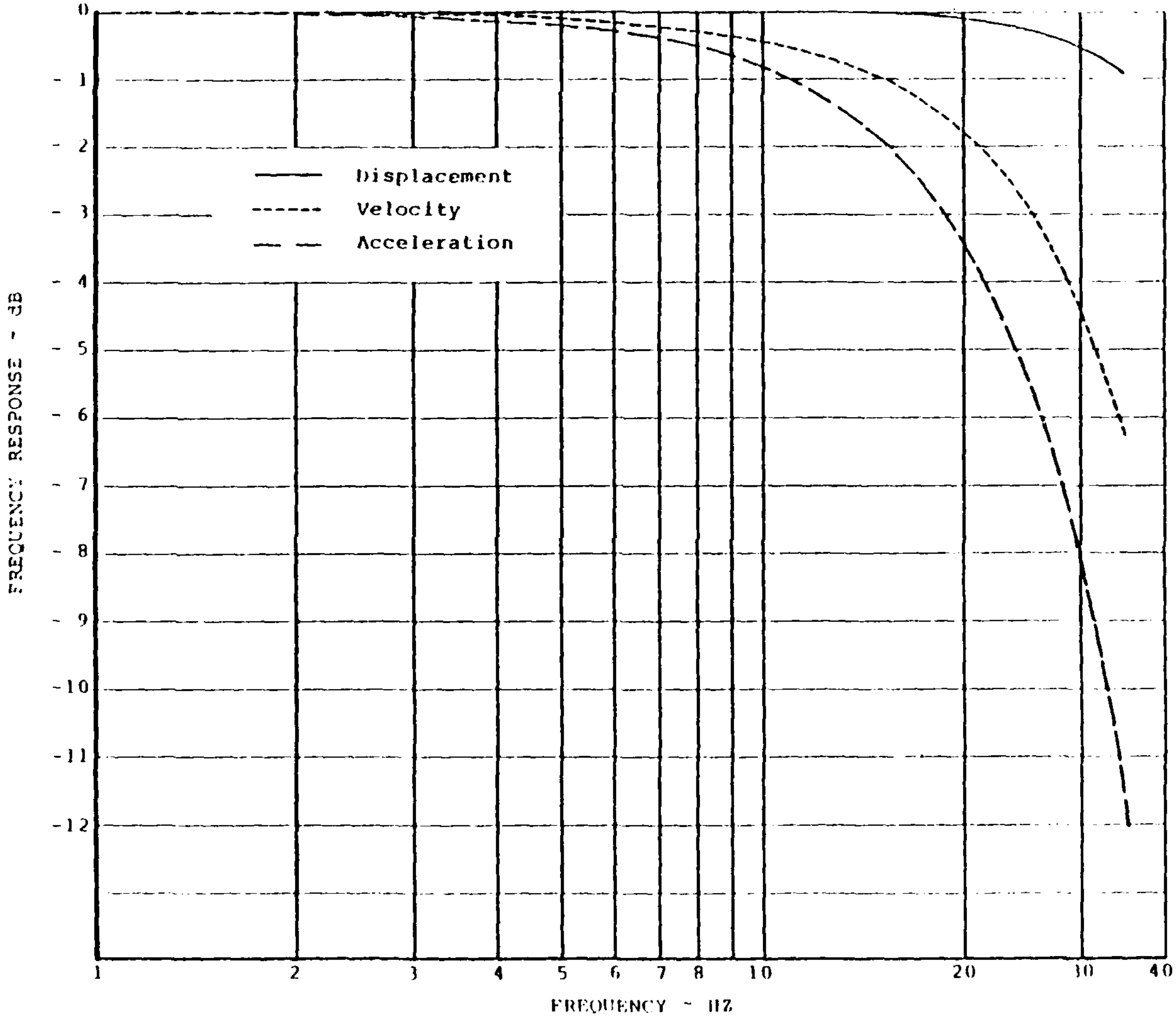


Figure 21. Frequency Response of 11-Point Smoothing as Applied in the HIFPD Program.

TABLE 20

DISTORTION FACTOR (FK) COMPUTED FROM MULTIPLE FREQUENCY SINE FUNCTIONS

f_o (Hz)*	$r = \frac{f_o}{f_s}$	F	Distortion Factor (FK) DISPL	VEL	ACCEL
2	.04	.9974	1.0000	.9981	.9963
4	.08	.9895	1.0000	.9925	.9851
6	.12	.9765	.9999	.9831	.9667
8	.16	.9584	.9997	.9700	.9413
10	.20	.9355	.9993	.9532	.9093
12	.24	.9079	.9985	.9327	.8713
14	.28	.8759	.9972	.9066	.8278
16	.32	.8399	.9953	.8809	.7796
18	.36	.8000	.9926	.8498	.7275
20	.40	.7568	.9888	.8154	.6724
22	.44	.7106	.9838	.7779	.6151
24	.48	.6618	.9975	.7376	.5567
26	.52	.6109	.9695	.6949	.4981
28	.56	.5583	.9597	.6500	.4403
30	.60	.5046	.9479	.6034	.3841
32	.64	.4500	.9340	.5556	.3305
34	.68	.3952	.9177	.5070	.2801
35	.70	.3679	.9086	.4826	.2563

*f_o applies only to an 11-point fit of data sampled at 500 samples per second; use r to determine FK for other fits and/or sample rates.

TABLE 21

STANDARD DEVIATION OF DIFFERENCE BETWEEN UNSMOOTHED AND SMOOTHED DISPLACEMENT DATA IN FEET

	TEST 172		TEST 173	
	x-axis	z-axis	x-axis	z-axis
Hip	.0028	.0028	.0027	.0030
Knee	.0028	.0039	.0034	.0041
Shoulder	.0077	.0041	.0080	.0046
Elbow	.0039	.0091	.0048	.0039
Head Point 1	.0085	.0058	.0090	.0060
Head Point 2	.0121	.0083	.0128	.0085
Piston	.0046	.0077	.0062	.0072
T1	.0089	.0045	.0093	.0038
Helmet 1	.0090	.0037	.0099	.0038
Helmet 2	.0082	.0035	.0086	.0038

SECTION 3

ANALYSIS OF NONPLANAR MOTION

Exposure to impact environments having significant lateral components of acceleration usually result in three dimensional responses.

A method was developed by the UDRI to solve for the instantaneous coordinates of points relative to a seat coordinate system (SCS). The method, documented in AMRL-TR-78-94, employs program POOCH to calculate the apparent coordinates of the focal point of each camera and the orientation of its optical axis and the film frame axes in the SCS. The results output by POOCH are input to program SLED to calibrate the digitized readings of observed points. SLED solves for the most likely point of intercept of the rays from each observed point to each focal point and calculates the distance between the rays at each solution point.

This method was applied to photodata collected during the DOT 6 Year Old Child comparison and the Whole Body Restraint-Lateral study. The latter also required the derivation of velocity and acceleration time histories from the displacement-time data. Program WBRL was developed to smooth the component displacement-time histories and to derive smoothed component and resultant velocity and acceleration time histories. Program WBR-L, with explanatory comments, is listed in Appendix B.

3.1 DOT 6 YEAR OLD CHILD COMPARISON

The Department of Transportation, under an interagency agreement, requested a comparative analysis of the effectiveness of three types of automotive child restraint systems, and a comparison of the inertial and kinematic responses of three types of surrogate six-year-olds while restrained with each of the three systems. The surrogates were two manikins of different manufacture and nine live anesthetized baboons whose general anthropometry approximated that of a six year old child.

The impact environments were developed with the AMRL/BBP Horizontal Impulse Accelerator Facility at WPAFB. The impact environments simulated were twenty and thirty miles per hour head on and fifteen and twenty miles per hour left lateral. Seventy-five test runs, including system performance tests, were conducted from 22 October 1975 thru 19 December 1975.

3.1.1 Photometric Data Acquisition

The primary objectives of the photometric data system were to:

- Develop a method for calculating three dimensional displacement of anthropometric points.
- Collect data on two high speed motion picture cameras mounted onboard the test vehicle.
- Apply the developed method to reduce the photodata to time histories of three-dimensional coordinate positions in the SCS of two points on the head of each subject.

The method developed to solve the time-SCS position data resulted in the programs POOCH and SLED. These programs required application of fixed reference fiducials and a survey of their coordinates in the SCS. The camera and range survey data from forward impact configurations and left lateral impact configurations are presented in Figures 22 and 23 respectively.

Photo recordings were recorded on two Milliken DBM-4B cameras fitted with 10 mm lenses. The cameras were operated at a nominal rate of 500 frames per second. Timing of the film was provided by exposure of the film edges to light emitting diodes excited simultaneously by a central pulse generator at 100 pulses per second.

Figures 24 and 25 illustrate typical scenes as observed by these cameras prior to forward and lateral impacts respectively.

CAMERA SURVEY DATA

Camera	Focal Point Coordinates (x, y, z; inches)	Azimuth	Elevation	Roll
6 (Forward)	(-41.1, 40.25, 42.5)	-33°	-18°	0°
7 (Forward)	(-40.6, -40.75, 43.0)	37°	-17°	0°

Angular Conventions:

Azimuth: Positive CW from x axis viewed from above.

Elevation: Positive incline above local horizontal.

Roll: Positive CW about optical axis.

RANGE SURVEY DATA

Reference Point Coordinates (x, y, z; inches)

Point	Runs 660 - 672	Runs 673 - 685	Runs 686 - 696	Runs 697 - 700
1		(45.47, -17.91, 45.22)	(45.04, -18.09, 45.25)	(45.59, -17.88, 45.25)
2		(45.62, - 3.91, 45.16)	(45.81, - 4.04, 45.25)	(45.78, - 3.81, 45.19)
3		(45.72, 10.09, 45.19)		
4			(45.69, 24.03, 45.47)	(45.84, 24.62, 45.25)
5	(0.66, -13.12, 3.84)	Constant throughout test period.		
6	(0.88, - 7.0 , 7.73)			
7	(0.88, 6.62, 7.88)			
8	(0.69, 12.75, 6.09)			
9	(0.91, 0.0 , 8.12)			
10	(0.09, 0.0 , 3.5)			

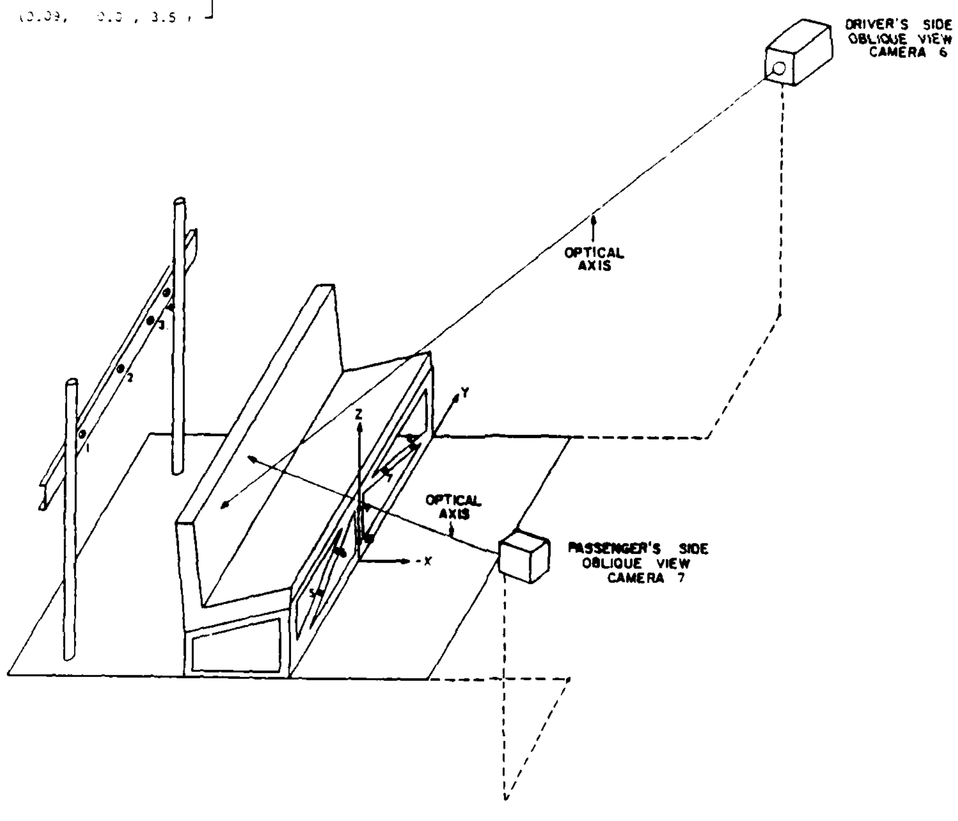


Figure 22. DOT Six-Year-Old Child Comparison Seat Coordinate System and Survey Data, Forward Impacts.

CAMERA SURVEY [illegible]

Camera	[illegible] Coordinates [illegible]	Azimuth	Elevation	Roll
7 Lateral	[illegible] 43.	[illegible]	[illegible]	[illegible]
8 Lateral	[illegible] 44.	[illegible]	[illegible]	[illegible]

Angular Conventions

Azimuth: Positive [illegible] from X axis viewed from above.

Elevation: Positive inclined above local horizontal.

Roll: Positive [illegible] about optical axis.

RANGE SURVEY DATA

Reference Point Coordinates (X, Y, Z inches)

Point	Runs 708 - 716	Runs 717 - 726	Runs 727 - 74[illegible]
[illegible]	41.34, -15.75, 42.06)	41.19, -16.03, 43.[illegible]4	41.[illegible], -16.[illegible], 43.[illegible]4
[illegible]	41.2[illegible], - 1.7[illegible], 42.14)	41.08, - 2.03, 43.94)	40.81, - [illegible], 43.[illegible]4
[illegible]	41.1[illegible], 12.2[illegible], 42.22	40.[illegible]7, 11.97, 44.[illegible]	
[illegible]	41.[illegible], 26.2[illegible], 43.25)	40.94, 25.9[illegible], 44.06)	40.62, 2[illegible], 44.[illegible]
[illegible]	[illegible], -13.1[illegible], [illegible].34)	Constant throughout test period.	
[illegible]	[illegible], - [illegible], [illegible]		
[illegible]	[illegible].88, [illegible].62, 7.78)		
[illegible]	[illegible].64, 12.7[illegible], 6.09)		
[illegible]	[illegible].41, [illegible], 8.12)		
[illegible]	[illegible]2.09, [illegible], 3.[illegible]		

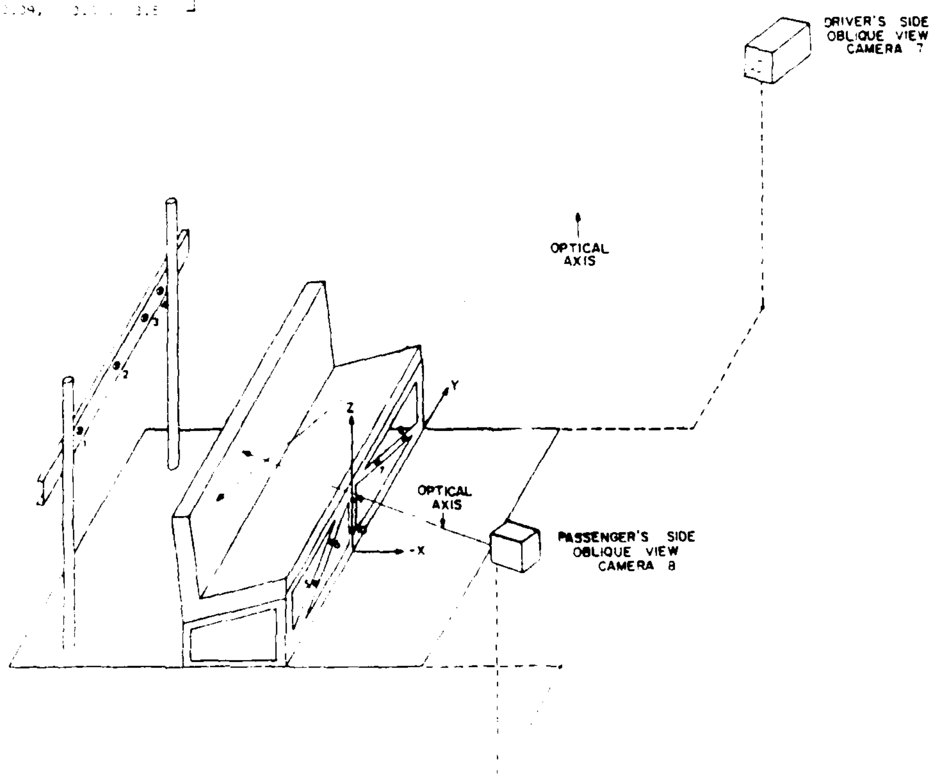


Figure 23. DOT Six-Year-Old Child Comparison Seat Coordinate System and Survey Data, Lateral Impacts.

Figure [illegible]. Typical Scene Prior to Forward Impact as Observed by Cameras [illegible] (Upper) and [illegible].

Figure 25. Typical Scene Prior to Lateral Impact as Observed by Cameras 7 (Upper) and [illegible].

3.1.2 Data Reduction

Reduction of the recorded data to displacement-time histories required digitization, in the projected image coordinate system (PCS) of the coordinates of fixed reference fiducials and fiducials on the heads of the subjects, and electronic data processing of the digitized data by POOCH and SLED.

Digitizing was accomplished on a Producers Service Corporation model PVR film analyzer (PVR) which was interfaced to a teletype terminal equipped with a paper tape punch station (TTY).

The film was mounted on the PVR and was transported until the first time pulse (t=0) was observed. The film was transported in reverse until the twelfth frame before the t_o pulse to compensate for the film path displacement of the LED from the exposure frame in the gate. The frame counter was reset to 0000.

The origin of the projected image coordinate system was located by numerically bisecting the major and minor dimensions of the projected frame and resetting the counters to zero at that point. The PCS coordinates of all observed reference fiducials were then digitized by locating the cursors over the center of each and depressing the record switch. The operator noted the code number of eacn observed fiducial as it was digitized. These values were later processed by POOCH to locate and orient the camera for the data from this test.

The operator then digitized the PCS coordinates of four reference fiducials, previously selected as being observable throughout the event, and the four points on the heads of the subjects. The resulting table of data was in the form of the following format throughout the program. During lateral impacts only one subject was exposed. When films from these tests were digitized the reading of the chin fiducial was repeated two additional times to fill the file.

LINE 1:

Columns	Field	Data
1- 5	I5	Frame number.
6-12	F7.0	PCS abscissa of reference point A.
13-19	F7.0	PCS ordinate of reference point A.
20-26	F7.0	PCS abscissa of reference point B.
27-33	F7.0	PCS ordinate of reference point B.
34-40	F7.0	PCS abscissa of reference point C.
41-47	F7.0	PCS ordinate of reference point C.
48-54	F7.0	PCS abscissa of reference point D.
55-61	F7.0	PCS ordinate of reference point D.

LINE 2:

1- 5	I5	Frame number.
6-12	F7.0	PCS abscissa of point on forehead, passenger seat.
13-19	F7.0	PCS ordinate of point on forehead, passenger seat.
20-26	F7.0	PCS abscissa of point on chin, passenger seat.
27-33	F7.0	PCS ordinate of point on chin, passenger seat.
34-40	F7.0	PCS abscissa of point on forehead, driver seat.
41-47	F7.0	PCS ordinate of point on forehead, driver seat.
48-54	F7.0	PCS abscissa of point on chin, driver seat.
55-61	F7.0	PCS ordinate of point on chin, driver seat.

NOTE: Points tracked on baboons were the head accelerometer and the tip of the snout.

After the data were digitized from frame zero the film was advanced to frame 001 and the points were again digitized in the same sequence. This procedure was repeated for each frame until one of the fiducials on the head of one of the subjects became unreadable.

The digital files recorded on paper tapes were communicated to the CDC computer system at Aeronautical Systems Division's Digital Computation Facility (ASD/AD) from a TTY via data modem and voice quality lines. The files were edited to correct format and/or character errors and were copied to disk storage and card punch. The card files were maintained as backup in case the disk files had been inadvertantly purged.

The files were amended by insertion of camera location and orientation data output by POOCH, and the addition of the fixed reference fiducial SCS coordinates, the film frame-time equivalence table, and the interpolation interval and test run number as required by SLED.

The binary file of SLED was attached and executed. The output was copied, in batch mode, to a printer and card punch.

The results were visually checked for obvious errors. If the solutions evidenced no apparent discontinuities and the miss-distances at the solution points were less than 0.25 inch, the card deck containing the SCS solutions was prepared to generate plots. The plots generated presented y and z displacements versus x displacement.

3.2 WHOLE BODY RESTRAINT-LATERAL

Description of relative motion of anthropometric points of the torso, head, and extremities during laboratory simulations of impact environments are essential to the development and verification of predictive models. One method of describing the motion of these points is to track each point as a function of time with two or more motion picture cameras, quantify or evaluate the coordinates of their images as projected, and from these projected image coordinates calculate the loci of the points in the seat coordinate system. This method was applied during the Whole Body Restraint-Lateral (WBRL) Impact Study conducted by the Biomechanical Protection Branch of the AF Aerospace Medical Research Laboratory (AMRL/BBP). The experimental tests were conducted on the

Horizontal Impulse Accelerator facility in Building 824 at Wright-Patterson Air Force Base, Ohio between March and July 1977.

3.2.1 Seat Coordinate System

The seat coordinate system (SCS) was a left handed three-dimensional, mutually perpendicular system having its origin at the intercept of the seat centerline and the line of intersection of the seat pan upper surface and the seat back forward surface. The positive senses of the axes were to the rear (x axis), to the left (y axis), and upward (z axis) as illustrated in Figure 26.

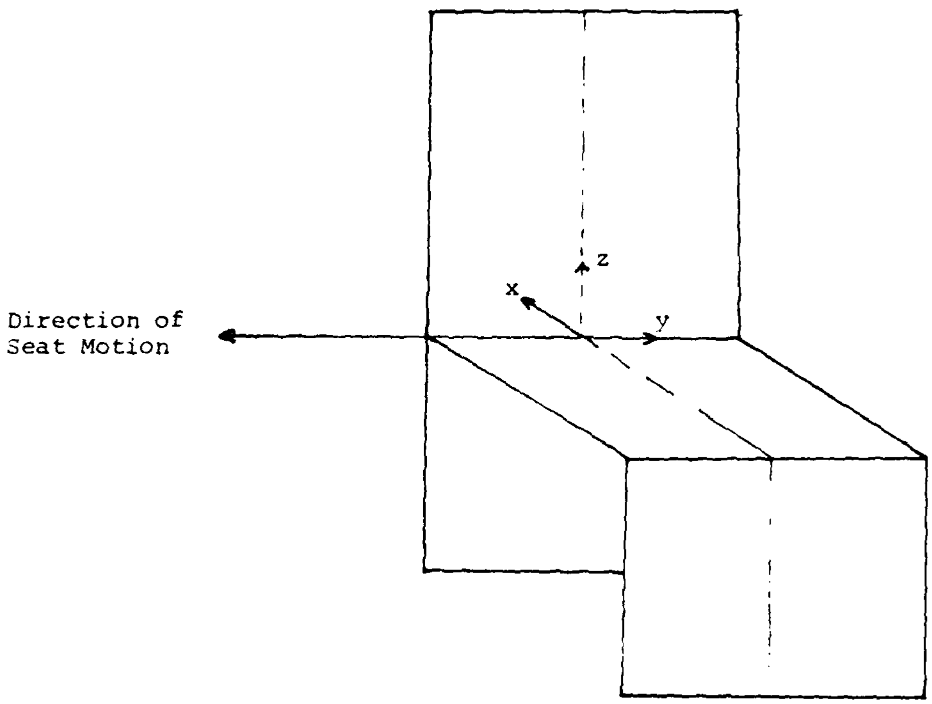


Figure 26. WBR-L Seat Coordinate System (SCS).

3.2.2 Camera Locations

Photographic records of the responses of the test subjects were acquired by four Milliken 16 mm cameras operating at nominal exposure rates of 500 frames per second. All four cameras were mounted onboard and were located and oriented such that each of the fiducials located on the nine anthropometric points to be tracked were observable by two of the cameras throughout the impact and response periods. The location and orientation scheme of the cameras is illustrated in Figure 27, and the coordinates of the focal points and orientations of optical axes are presented in Table 22.

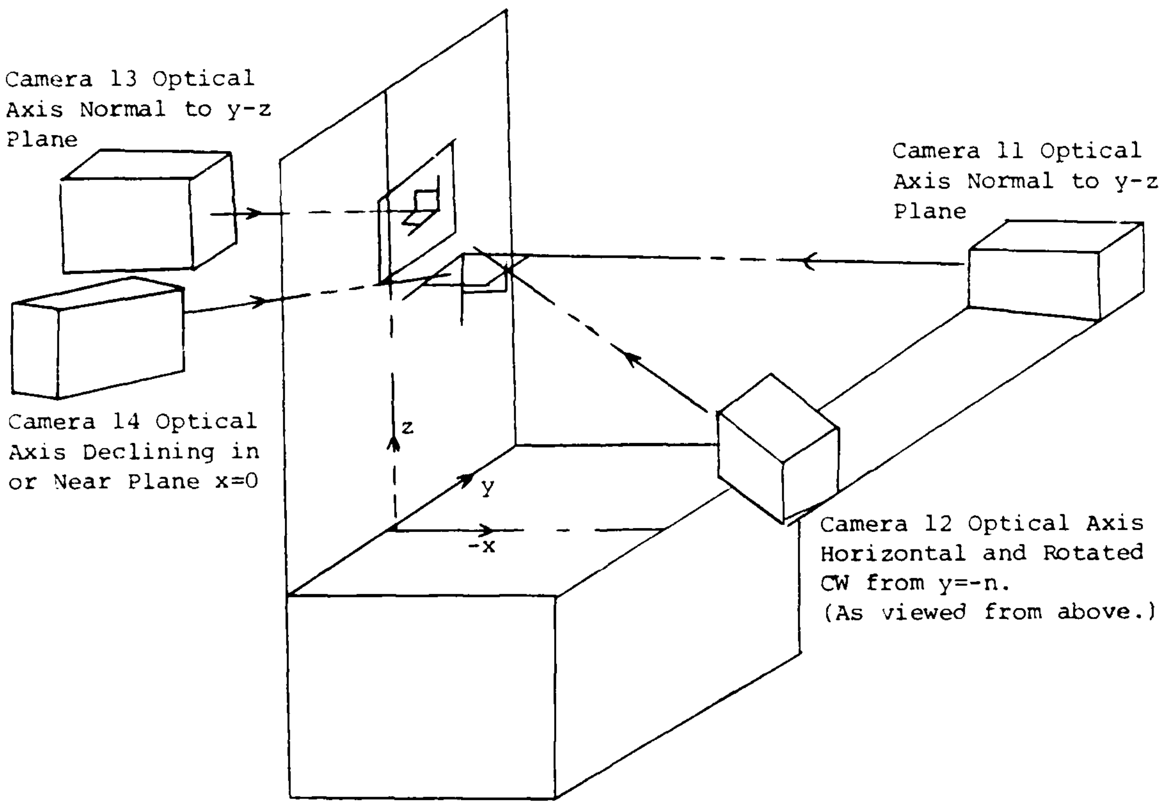


Figure 27. Schematic of Camera Locations and Orientations, WBR-L.

TABLE 22

SURVEY OF PHOTOMETRIC RANGE CAMERA DATA, WBFL

	Station 11	Station 12	Station 13	Station 14
Camera Type	DMB-4B	DBM-4B	DBM-44	DBM-44
Camera S/N	4721	4720	44700-1	44697-1
Lens Focal Length (NOMINAL)	10 mm	10 mm	10 mm	10 mm
Focal Point Coordinates, Measured:				
x (ft)	-4.327	-4.245	1.333	.030
y (ft)	.419	-1.051	.510	-1.165
z (ft)	1.402	1.402	2.000	2.575
Lens Focal Length (Derived)	10.93 mm	11.96 mm	10.06 mm	7.69 mm
Focal Point Coordinates (Derived)				
x (ft)	-4.731	-4.869	1.340	0.065
y (ft)	0.578	-1.004	0.54	-1.161
z (ft)	1.389	1.454	1.991	2.570
Optical Axis Orientation (Derived)				
AZIMUTH (Deg)	-1.166	18.618	-179.604	- 95.082
ELEVATION (Deg)	-1.556	-1.482	- .011	-167.493
Camera Frame Orientation (Derived)				
Roll (Deg)	1.629	0.799	.034	.012

3.2.3 Data Acquisition

The data acquisition mission consisted of three distinct tasks:

1. Documentation of anthropometric measurements of each subject.
2. Tracking fiducial application, measurement, and documentation.
3. Cine recording of the tracking fiducials during the impact and response events.

Anthropometry of each test subject was measured and documented by AMRL/HED.

Tracking fiducial application, measurement and documentation were accomplished prior to each test run by the UDRI representative. Tracking fiducials were located as follows.

The suprasternal notch was located by palpation and marked with a nylon tip pen.

The lower end of the sternum was located by palpation and marked.

Two arcs of 10 cm radius were struck from the mark on the suprasternal notch to the right and left clavicles and were marked.

One-inch-diameter fiducials, printed in alternating black and yellow quadrants and having a one-sixteenth inch hole at the center, were placed over these four marks.

With the subject's head erect, a fiducial approximately three-eighths inch high and one-inch wide was centered on the sagittal plane of the nose at the level of the pupils. A fiducial of similar size was located at the level of the pupils at each lateral orbital rim.

Two additional tracking fiducials were previously mounted to a leather appliance which was strapped to the subject's pelvis. Initially these fiducials were placed on the subject over the anterior superior iliac spines. This proved to be unsatisfactory

because the fiducials on several subjects were obscured by abdominal skin folds when the subject was seated.

The last fiducial was intended to track the motion of the first thoracic vertebra (T-1). With the subject's head bowed forward the spinous process of the seventh cervical vertebra (C-7) was located by palpation and was followed as the subject erected his head. The fiducial was then placed over this point which, with the head erect, overlayed T-1.

With the subject seated in a mockup of the test seat relative dimensions were read with an anthropometer and recorded. Dimensions taken were:

R.H. eye fiducial - L.H. eye fiducial
R.H. eye fiducial - Nose fiducial
L.H. eye fiducial - Nose fiducial
Suprasternal notch fiducial - Lower sternum fiducial
Suprasternal notch fiducial - R.H. clavicle fiducial
Suprasternal notch fiducial - L.H. clavicle fiducial
Suprasternal notch fiducial - R.H. pelvic fiducial
Suprasternal notch fiducial - L.H. pelvic fiducial
Lower sternum fiducial - R.H. clavicle fiducial
Lower sternum fiducial - L.H. clavicle fiducial
R.H. pelvic fiducial - L.H. pelvic fiducial
R.H. clavicle fiducial - L.H. clavicle fiducial

After the subject was instrumented and seated in position, coordinates (in the seat coordinate system) of the suprasternal notch fiducial, the R.H. trageon, and the lower, forward, inboard corner of the Nine Transducer Accelerometer Pack (9TAP) were read and recorded. The 9TAP was mounted on the R.H. side of a welding mask headband which was secured by straps under the chin and the base of the occiput. It contained three linear accelerometers at the origin and two at the end of each arm aligned with each of the three axes of the head and was designed to yield time histories of linear acceleration in three axes and angular accelerations about those axes.

Prior to the first test, fixed reference fiducials were mounted on the test fixture. These fiducials are identified in Figure 28, and their coordinates are listed in Table 23.

Cine recording of the responses of the subjects were recorded from t=-2 seconds to t=2 seconds. The four Milliken cameras were remotely operated by circuits in the photo instrumentation control console which was programmed into the countdown sequence. Timing was provided by a pulse generator which simultaneously excited an LED in each of the cameras at the rate of one hundred pulses per second.

Synchronization of time among the films was accomplished by a strobe flash, observable by all cameras, initiated at t=0.

3.2.4 Data Reduction

The desired results of the data reduction effort were time histories of coordinate positions of the tracked points and the velocities and accelerations derived thereform. The system used was a modified photo theodolite space position solution system. The phototheodolite system assumes synchronized exposure of films from two or more cameras. Since the cameras used were not synchronized, the system was modified to synchronize projected film frame images by linear interpolation of projected film frame coordinates between frames at fixed time intervals.

The overall data reduction task required three subtask areas, film editing, projected image digitizing, and electronic data processing.

3.2.4.1 Film Editing

Critical to the processing of the photo data were timing, legibility of reference and tracking fiducials, and documentation of any anomalies that might occur.

Each film was viewed on a light table to assure that there was no erratic behavior of film transport during recording. This was accomplished by sampling the film intervals between .01 second LED images on the film. If no significant deviations were

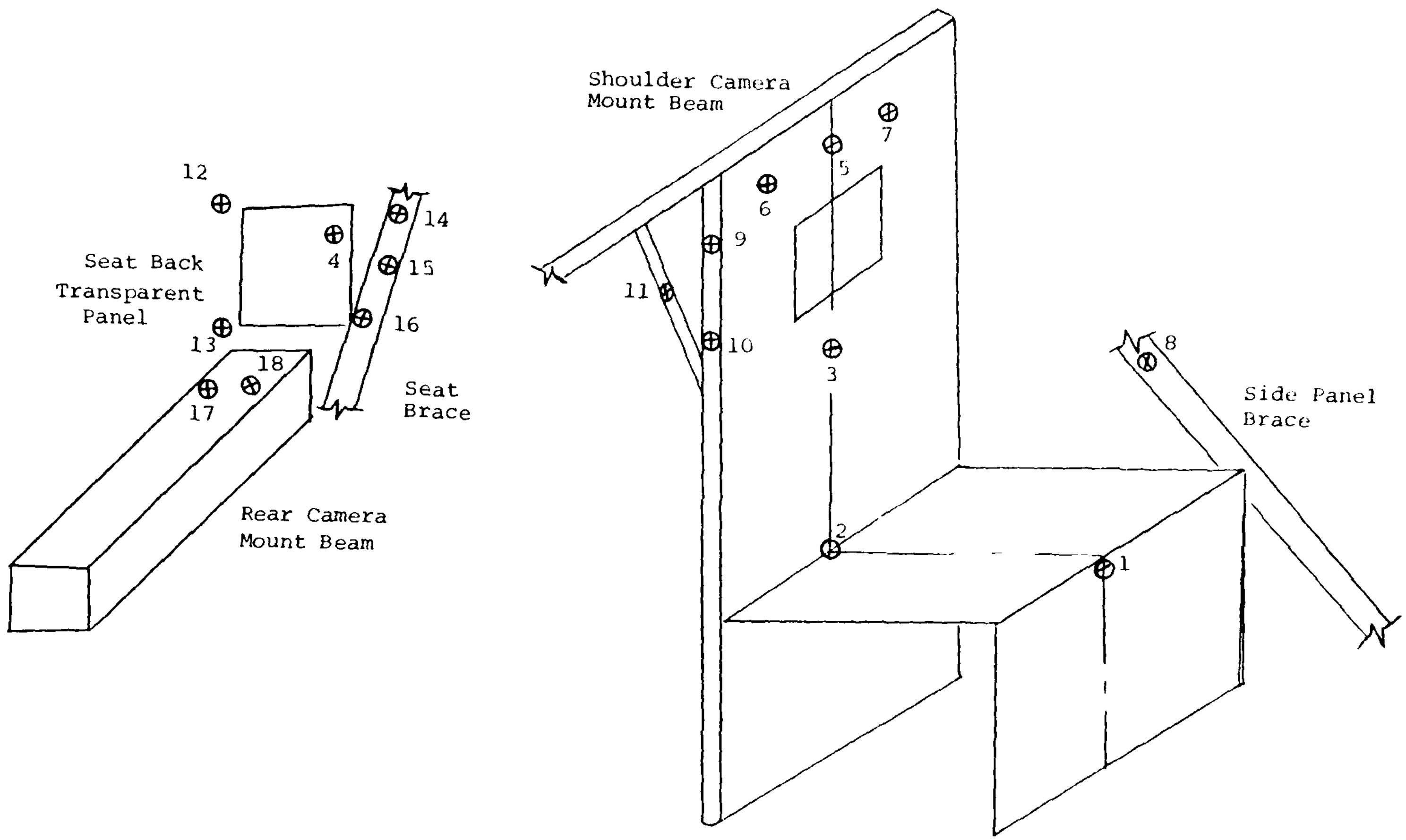


Figure 28. WBR- L Reference Fiducials Schematic.

TABLE 23

WBRL REFERENCE FIDUCIAL COORDINATES (CM)

Ref. No.	X	Y	Z
1	-45.0	0.0	- 2.5
2	0.0	0.0	0.0
3	0.0	0.0	45.2
4	0.0	0.0	70.0
5	0.0	0.0	91.2
6	0.0	-10.2	91.2
7	0.0	10.2	91.2
8	-43.7	45.0	39.5
9	5.6	-16.3	79.1
10	5.6	-16.3	63.8
11	5.2	-22.4	74.1
12	1.0	17.1	73.2
13	1.0	17.2	54.2
14	8.7	- 0.4	72.3
15	9.7	0.5	67.4
16	11.1	1.0	60.6
17	27.9	16.4	50.9
18	27.8	10.8	50.9

noted, the average frame rate was calculated. Since the cameras employed were pin registered, and a loop of 11 to 12 frames was required between the pulsed LED and the shutter, absolute timing was not possible.

Time zero was, by definition, the first frame in which the strobe flash was observable. Given a nominal frame rate of 500 frames per second (500 fps) the maximum synchronizing error was 2 milliseconds for each camera. However, given the shutter openings of 140° the maximum error between two given cameras becomes 1.22 milliseconds;

$$\left(\frac{360° - 140°}{360} \times .002 \quad \text{sec}\right)$$

3.2.4.2 Projected Image Digitizing

Films from cameras mounted onboard at stations 11, 12, 13, and 14 were digitized. The origin of the film frame coordinate system was determined by bisecting the horizontal and vertical centerlines of the projected film frame images from ten test runs. The readings of reference fiducials were tabulated and the average reading of each fiducial was calculated. These were defined as the table of standard readings used to set the scales for digitizing.

The film was mounted on the Producers Service Corporation (PSC) model PVR film analyzer and the scaling system was rotated until the cursors were in alignment with the projected film frame image at the frame defined as t=0. The cursors were set over the image of a reference fiducial and the scales were set to zero. The cursors were then translated until the negative values of the standard reading for that fiducial were counted and were again reset to zero. The readings of all reference fiducials were taken to assure that they were all within $\pm$20 counts (.02 inches) of the values in the table of standard readings.

From Cameras 11 and 12 the data points were digitized to punched paper tape in the format (I5, 8F7.0/5X, 8F7.0/5X, 8F7.0). The "I5" was the frame number. Each of the "8F7.0" formats was composed of four pairs of "-x, y" values in the projected film frame coordinate system. This was chosen to simplify the reading since the cameras at stations 11 and 12 were rotated onto their left sides to improve the field of view.

The PSC model PVR is constrained to read +x to the right of the operator and +y upward. Since the cameras at stations 11 and 12 were rotated to their left sides, the operator's view of the film frame was as illustrated in Figure 29. Thus with the PVR programmed to digitize Frame Number and four pairs of y, x values, the net result was the format presented above.

The first line of readings (I5, 8F7.0) contained the frame number and four "-x, y" film frame coordinates of fixed reference points. The first format "5X, 8F7.0/" contained the repeated frame number (5X) and four pairs of film frame coordinates (-x, y) of the suprasternal notch, lower sternum, R.H. clavicle and L.H. clavicle fiducials. The second format "5X, 8F7.0" contained the repeated frame number and four pairs of film frame coordinates (-x, y) of the R.H. pelvis, L.H. pelvis, R.H. eye, and nose fiducials.

For camera stations 13 and 14 the data points were digitized to punched paper tape in the format (I5, 8F7.0/5X, 8F7.0). For these views the PSC PVR was programmed to punch the coordinate pairs in "x, y" format since camera 13 was mounted upright and camera 14 was inverted.

The first line of readings (I5, 8F7.0) again contained the film frame number and pairs of x, y readings of four fixed reference points. The second line (5X, 8F7.0) contained the repeated frame number and the reading of the coordinates of the T1 fiducial read four times. This was done to satisfy the requirements of the preprogramming of the PVR and input format to Program SLED.

Figure 29. Projected Film Frames From Cameras 12 (Upper) and 11 as Viewed by Operator, WBR-L.

The operator's view of the projected images of films from cameras 13 and 14 is illustrated in Figure 30.

3.2.4.3 Electronic Data Processing

Electronic data processing required a sequence of related operations which could be broadly broken down into the areas of data preparation, computation and plotting, and review of results.

Three computer programs were required to achieve the results. Program POOCH was used to determine the apparent location and orientation of each of the four cameras. Program SLED was employed to solve for the most likely point of the intercept in the three-dimensional SCS of rays from each pair of cameras to each tracked point. Program WBRL was employed to calculate time histories of smoothed coordinate positions of each of the tracked points, smoothed component and resultant accelerations of each of the tracked points, and orthogonal projections of the relative positions of the right lateral orbital rim fiducial and the nose fiducial.

The results of these calculations were printed on hard copy and written on magnetic tape for offline plotting.

Programs POOCH and SLED are described in detail in AMRL-TR-78-94 "Photometric Methods for the Analysis of Human Kinematic Responses to Impact Environments."

Data Preparation: Preparation of data for input to program POOCH required digitization of projected image coordinates of each of the fixed reference points and transcribing these values together with the measured coordinates in the SCS of the points into tabulating cards. The approximate measured coordinates in the SCS of the focal point of the camera and the nominal focal length of the lens were also transcribed to accounting cards. These cards were then merged with system control cards and the binary program cards and transmitted to ASD/AD, Bldg. 676, WPAFB for processing.

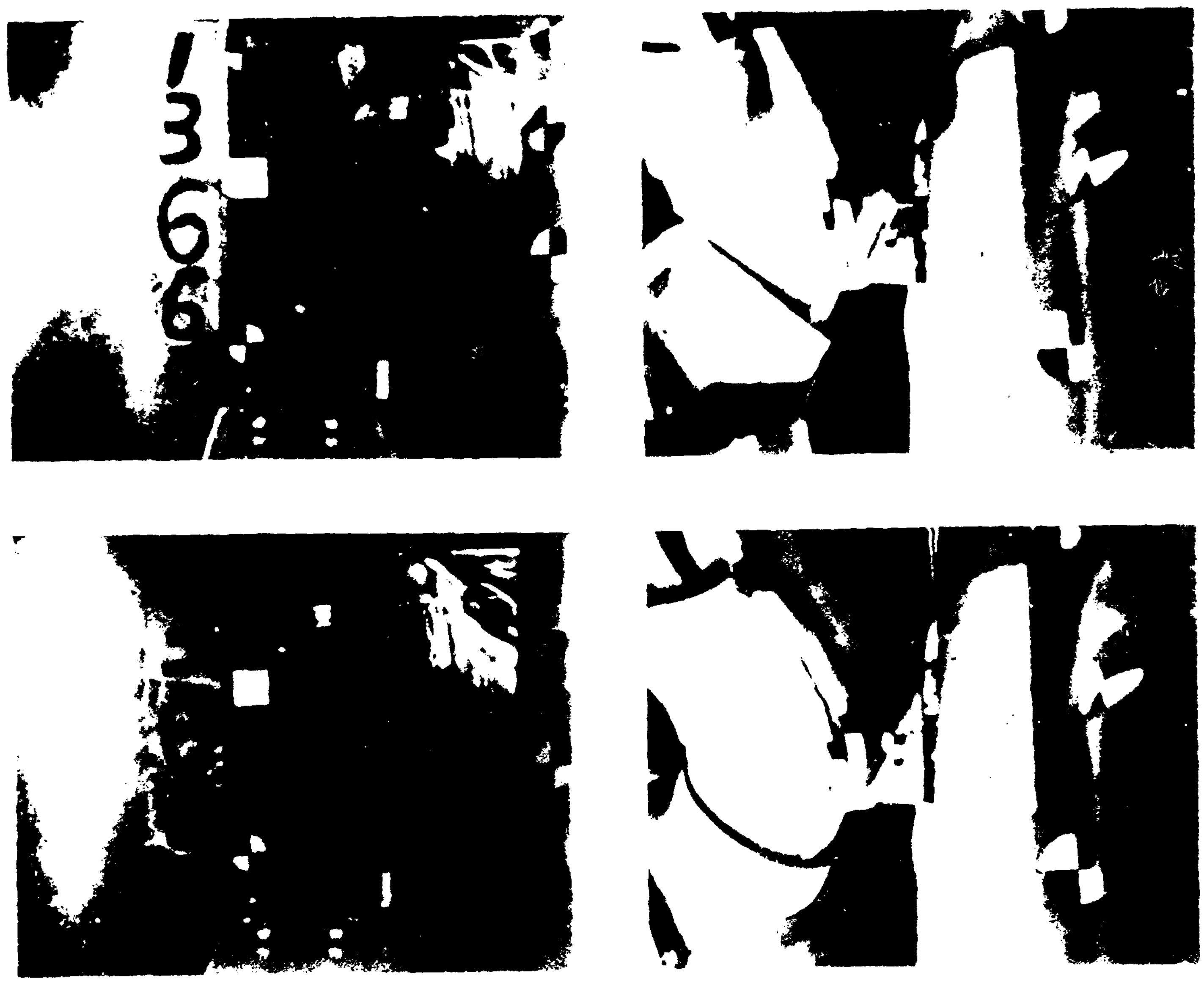


Figure 30. Projected Film Frames From Cameras 13 (Left) and 14 as Viewed by Operator, WBR-L.

Processing of projected image coordinates to three-dimensional positions in the SCS required, in addition to the digitized readings, location and orientation data for each of the cameras, reference fiducial table as seen by each camera, and a film frame-time equivalence table. Cards containing these data were punched and merged with the required system control cards and were submitted to ASD/AD for processing with program SLED.

The tables and plots output by program SLED were reviewed for apparent gross errors. When none were observed, the card files punched by program SLED were merged with system control cards and submitted to ASD/AD for processing to smoothed time-SCS coordinates, velocities and accelerations by program WBRL which is presented in Appendix A. Tables and plots generated by program WBRL are presented in Appendices B through N.

Computation and Plotting: These functions were accomplished on the CDC systems at ASD/AD. The programs used have been previously referenced, however it is well to note that the program WBRL calls subroutines from the system library to prepare and write the tapes used for offline plotting.

Review of Results: The coordinate solutions calculated by program SLED from the projected images of films from cameras 11 and 12 resulted in smooth time-displacement curves for the y and z components but were very erratic for the x component. Due to the shallow angle between the optical axes of these cameras (approximately 19.8 degrees) even slight reading error resulted in large fore and aft errors (x coordinates). These errors became even more magnified in the differentiation to x components of velocity and acceleration.

A statistical analysis of the miss distances between the rays constructed from both cameras at the solution points was accomplished by program SLED. The values of mean error and standard deviation from the mean calculated for each of the tracked points for each test is tabulated at the start of each of the data results appendices. The mean error and standard deviation

from the mean for the tracked points for all tests considered are presented in Tables 24 and 25.

The above data indicated that the SCS solutions for the T-1 fiducial were relatively poor. The high standard deviations for this point may be due to:

1. Refraction of rays passing through the seat back window.
2. Glare from both window and fiducial as the seat traveled past individual lamps.
3. Angle between the surface of the fiducial and the ray to camera 14 was very small.

In general the fiducial surfaces were very reflective and difficulty was experienced with recognizing the centers of all at various times throughout the tests.

Calculated values of velocity and acceleration were probably degraded as a function of frequency. A study by Mr. Mohlman of error induced by smoothing displacement, velocity, and acceleration data with a moving quadratic arc fit to eleven points will soon be published.[2] The study was based in part on the analysis of sinusoidal displacement data sampled at 2 millisecond intervals. The sinusoidal frequencies analyzed were varied from 2 Hz to 35 Hz. The results of this portion of Mr. Mohlman's study were presented in Figure 21 and Table 20.

TABLE 24

ANALYSIS OF MISS DISTANCE BETWEEN RAYS AT SOLUTION POINTS, HUMAN SUBJECTS

	Number of Points	Mean Miss Distance (inches)	Standard Deviation From Mean (inches)
Suprasternal Notch	3728	.066	.068
Lower Sternum	3728	.077	.146
R.H. Clavicle	3728	.117	.149
L.H. Clavicle	3728	.118	.169
R.H. Pelvis	3727	[illegible]	[illegible]
L.H. Pelvis	3727	.088	.083
R.H. Eye	3727	.104	.082
Nose	3727	[illegible]	[illegible]
T-1	3702	[illegible]	.244
TOTALS	33522	[illegible]	.140

TABLE 25

ANALYSIS OF MISS DISTANCE BETWEEN RAYS AT SOLUTION POINTS, MANIKIN SUBJECTS

	Number of Points	Mean Miss Distance (inches)	Standard Deviation From Mean (inches)
Suprasternal Notch	3363	.060	.057
Lower Sternum	3363	.055	[illegible]
R.H. Clavicle	3363	.097	[illegible]
L.H. Clavicle	3363	.080	[illegible]
R.H. Pelvis	3364	.066	[illegible]
L.H. Pelvis	3364	[illegible]	[illegible]
R.H. Eye	3364	[illegible]	[illegible]
Nose	3364	[illegible]	[illegible]
T-1	3301	.444	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]

SECTION 4
PICTOGRAPHIC PRESENTATION

A need was seen to exist for a method of presenting, in a comprehensive manner, the sequential relative displacements of body segments as they respond to impact inputs. Program RSD was developed to process data, digitized from selected frames of motion picture recordings of laboratory simulations of $-G_x$ impacts, to a series of six time-incremented pictograms of body segment positions and restraint harness strap displacements relative to the seat.

This process was developed for the Biomechanical Protection Branch of the AF Aerospace Medical Research Laboratory (AMRL/BBP) located at Wright-Patterson Air Force Base (WPAFB), Ohio.

It was developed to minimize the manual effort required to convert digitized data to plotted pictograms. The processing program is written in FORTRAN language and utilizes library routines available on the CDC computer systems at Aeronautical Systems Division's Digital Computation Facility (ASD/AD) at WPAFB.

4.1 PROGRAM RSD INPUT REQUIREMENTS

This section describes the content and format of the data required to execute the program RSD. This program draws six graphs on the CALCOMP plotter which show the position of the head, shoulder, elbow, wrist, hip, knee and ankle at six time points during the test. The six graphs are plotted on a report size page (6-1/2 by 9 inches.

Execution of the program RSD requires the CCAU and CCPLOT1036 CALCOMP plot libraries. The CALCOMP plot output file is written on file TAPE7.

The first eight cards described below define the test parameters and the remaining six sets of six cards each define the input data at the six time points. The variable names used in the program are included with the data description. All references to the y axis in this text and in the program source listing (Appendix C) should be interpreted as the chair z axis.

Card Number 1 -- Title Card

Columns	Format	Variable Name	Description
1-60	6A10	TITLE	Title or caption printed below the set of six graphs. This title should be centered in the 60 column field.

Card Number 2 -- MISC. data in inches

1- 5			Card ID, — not read by the program	
6-12	F7.0	DPS	Distance between Lexan panel and seat side planes	
13-19	F7.0	DSC	Distance from seat side fiducial plane to seat center line	
20-26	F7.0	DPF	Distance between fiducials on Lexan panel	
27-33	F7.0	DSF	Distance between seat side fiducials	
34-40	F7.0	XSB	x shoulder belt attachment point	relative to seat origin
41-47	F7.0	YSB	y shoulder belt attachment point	relative to seat origin
48-54	F7.0	XLB	x lap belt attachment point	relative to seat origin
55-61	F7.0	YLB	y lap belt attachment point	relative to seat origin
62-68	F7.0	XASSF	x aft seat side fiducial	relative to seat origin
69-75	F7.0	YASSF	y aft seat side fiducial	relative to seat origin

Card Number 3 -- Breadths across fiducials (BAF) to be tracked; data are in counts.

Columns	Format	Variable Name	Description
1- 5			Card ID
6-12	F7.0	BAF(1)	Hip
13-19	F7.0	BAF(2)	Knee
20-26	F7.0	BAF(3)	Ankle
27-33	F7.0	BAF(4)	Shoulder
34-40	F7.0	BAF(5)	Elbow
41-47	F7.0	BAF(6)	Wrist
48-54	F7.0	BAF(7)	Trageon
55-61	F7.0	BAF(8)	Nose
62-68	F7.0	BAF(9)	Harness lap buckle
69-75	F7.0	BAF(10)	Shoulder harness

Card Number 4 -- Panel and seat fiducial data in counts.

1- 5			Card ID
6-12	F7.0	XPF	x - Lexan Panel FWD fiducial
13-19	F7.0	YPF	y - Lexan Panel FWD fiducial
20-26	F7.0	XPA	x - Lexan Panel AFT fiducial
27-33	F7.0	YPA	y - Lexan Panel AFT fiducial
34-40	F7.0	XSF	x - Seat Side FWD fiducial
41-47	F7.0	YSF	y - Seat Side FWD fiducial
48-54	F7.0	XSA	x - Seat Side AFT fiducial
55-61	F7.0	YSA	y - Seat Side AFT fiducial

Card Numbers 5 to 7 -- x, y coordinates used to compute radii of body elements (in counts).

Card Number 5

Columns	Format	Variable Name	Description
1- 5			Card ID
6-12	F7.0	X1(2)	x - First knee point
13-19	F7.0	Y1(2)	y - First knee point
20-26	F7.0	X2(2)	x - Second knee point
27-33	F7.0	Y2(2)	y - Second knee point
34-40	F7.0	X1(3)	x - First ankle point
41-47	F7.0	Y1(3)	y - First ankle point
48-54	F7.0	X2(3)	x - Second ankle point
55-61	F7.0	Y2(3)	y - Second ankle point

Card Number 6

Same format as Card 5 above for the x, y points for the shoulder [X1(4), etc.] and the elbow [X1(5) etc.].

Card Number 7

Same format as Card 5 above for the x, y points for the wrist [X1(6), Y1(6), etc.].

Card Number 8 -- Trageon and eye points required to compute the angle between the Trageon-Nose line and the head z-axis (in counts).

1- 5			Card ID	
6-12	F7.0	TX	x - Trageon point	measured when the head z-axis line is vertical
13-19	F7.0	TY	y - Trageon point	
20-26	F7.0	EX	x - Eye point	
27-33	F7.0	EY	y - Eye point	

(Note that the head and hip radii are computed using the center points from the 0 frame readings).

Film Data - the following six cards are required for each of the six plots.

Card Number 1 -- Time in milliseconds for this set of film data.

Columns	Format	Variable Name	Description
1- 5			ID or frame number (e.g. TIME =)
6- 8	A3	ITM	Time in milliseconds

Card Number 2

1- 5	I5		Frame number
6-12	F7.0	XSFF	x ~ Seat forward fiducial
13-19	F7.0	YSFF	y ~ Seat forward fiducial
20-26	F7.0	XAFF	x ~ Seat aft fiducial
27-33	F7.0	YAFF	y ~ Seat aft fiducial
34-40	F7.0	X(1)	x ~ Hip center point
41-47	F7.0	Y(1)	y ~ Hip center point
48-54	F7.0	X(2)	x ~ Knee center point
55-61	F7.0	Y(2)	y ~ Knee center point

Cards 3 through 6 have the same format as Card Number 2 above; they contain the x and y coordinates of the center point for each variable. The number in parenthesis is the index of the x and y arrays.

Card Number 3: Ankle(3), Shoulder(4), Elbow(5), and Wrist(6).

Card Number 4: Trageon(7), Nose(8), Lap Buckle(9), First Shoulder Harness(10).

Card Number 5: Next four Shoulder Harness points (11 to 14).

Card Number 6: Last two Shoulder Harness points (15 and 16).

(Note that the seven shoulder harness points are assumed to be listed in sequence from the buckle to the top shoulder point; that is, with increasing y values.)

4.2 FILM DIGITIZING PROCEDURE

The title to be printed below the pictograms (Card 1) was manually entered via the keyboard.

The [illegible] required (Card 2) were manually entered via the keyboard.

The values of breadths across fiducials (Card 3) were manually entered via the keyboard. BAF's 1 thru 8 were obtained from the pretest measurements form. BAF's 9 and 10 were considered to be constant, the shoulder strap center-center distances being 6.88 inches at the single tree and 1 inch just above the buckle loops. The distances between centers of the shoulder straps were measured prior to several tests to be constant with [illegible] from the single tree to the clavicles, and were [illegible] sidered to be parallel over that span [illegible]

The film record [illegible] ted on the Producers [illegible] ration Model [illegible]. The film was transported until the frame in which the strobe flash was first observed was projected and the frame counter was reset to zero. The film was transported forward in the single-frame mode, the operator noting the frame numbers at which the fourth, eighth, twelfth, sixteenth, and twentieth 0.01 second timing pulses appeared. The number of frames that the zeroth pulse was displaced from frame zero was subtracted from each of the [illegible] numbers to determine the frames from [illegible]

The film was transported backward while the operator observed the changing attitude of the subject's head. The number of the frame in which the head appeared to be erect was noted. Identification of this frame is strictly subjective, however, the error resulting from this judgment remains constant throughout the processing of data from each test.

After the film had been returned to frame zero the projected image coordinates of the reference fiducials on the lexan panel and the side of the seat pan were digitized in the order specified in the format for Card Number 4.

Two points were read at each of the joints on the subject's left arm and leg in the order specified in the formats for Cards 5, 6, and 7. These points were digitized to define the diameter of the circles representing the joints on the pictograms. The ankle of the subject was not in the field of view at frame zero, so the film was transported to a frame in which it was visible. The readings of the ankle points were read and a tracing was made in black ink on clear acrylic sheet of the fiducials on the ankle, knee, and intermediate point on the lower leg. The tracing also included the outline of the shin. This overlay was later used to locate the ankle fiducial when it was outside the field of view.

The film was transported to the frame noted as the one in which the head was erect and the coordinates of the fiducials at the trageon and nose were digitized as specified in the format for Card Number 8.

The film was returned to frame zero. At this point it is well to note the possibility that on some films the synchronizing flash can be bright enough to wash out the images of some of the fiducials. Had this occurred, time zero data would have been digitized from frame -1 (99999 on counter).

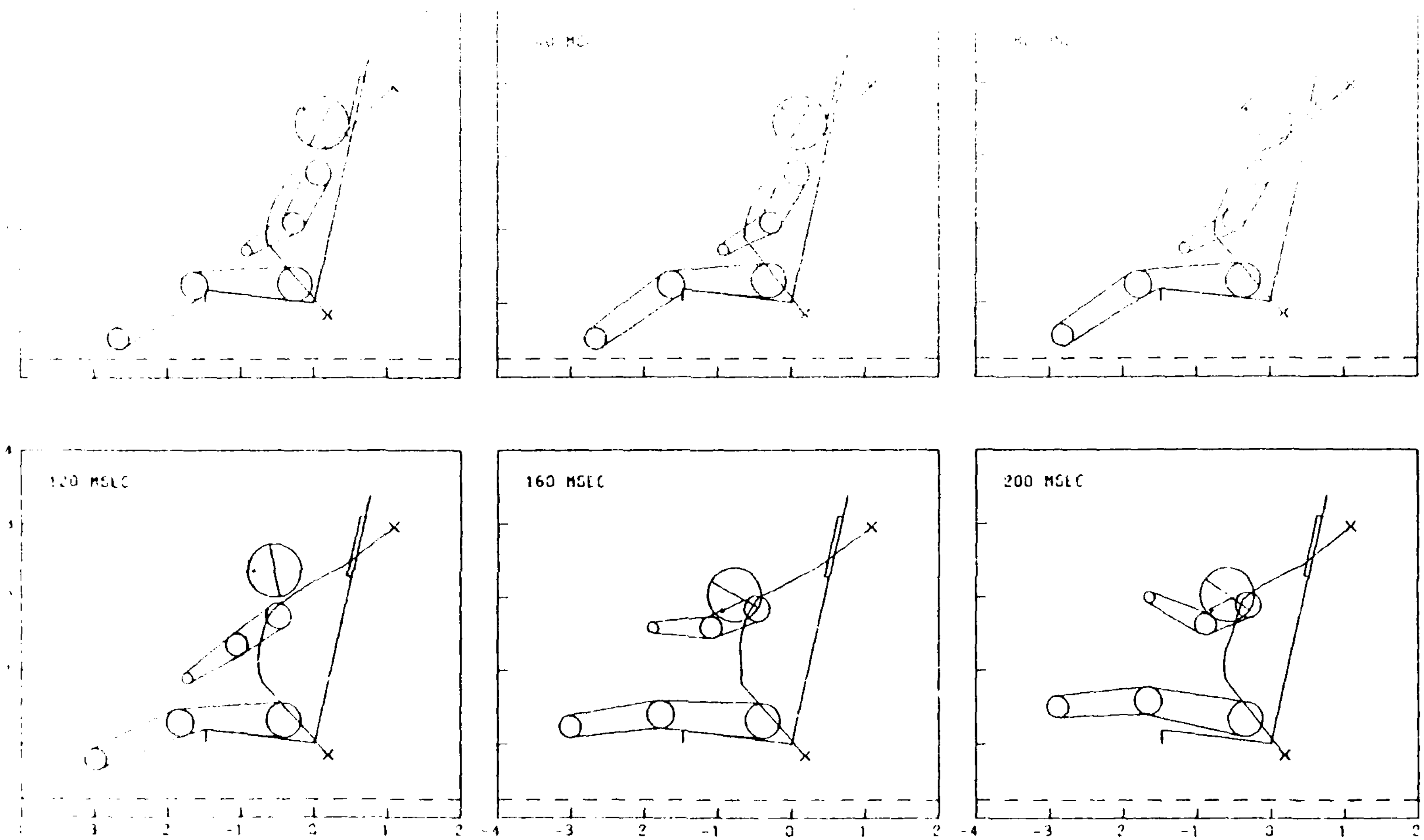
Time after initiation (msec) was entered manually via the keyboard as specified in the format for Film Data Card Number 1. The coordinates of the projected images were digitized in the order specified in the formats for Film Data Card Numbers 2 thru 6. All points on the seat and the subjects were defined by the fiducials with the exception of the shoulder, the elbow, and the wrist. As the arm elevated, the arm segments demonstrated rotary motion causing the fiducials on the elbow and wrist to rotate forward relative to the image of the arm. (Dummies with pinned joints do not demonstrate this rotation). At the shoulder, elbow and wrist

the points digitized were the estimated geometric centers of the images of the joints.

The first point digitized on the harness was the center of the buckle. The second, third, and fourth points were digized upward along the left shoulder strap between the buckle and the clavicle. The fifth, sixth, and seventh points were digitized upward (rearward) along the left shoulder strap between the clavicle and seatback.

4.3 RESULTS

The pictograms generated by the test case are illustrated in Figure 31. The format and the presentation of the body segment positions appear to accurately reflect the projected images in the film frames from which the data were extracted. The projection of the shoulder strap, as plotted, does not accurately reproduce the observed path of the strap. A need to review the technique used to digitize the strap data, and to improve the method of fitting a curve to the data is indicated.



F 111 10 GX GENERIC RESTRAINT TEST 1838 SUBJECT A1

Figure 41. Pictograms of Displacements of Body Segments and Restraint Harness as a Function of Time.

APPENDIX A

PROGRAM HIFPD

```
      PROGRAM HIFPD(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      DIMENSION     RES(302),VEL(302),WS(302),WH(302),WS2(302),WH2(302),
     1 HEADL(8),HEADR(8),HEADC(8),DATA(1024),           YNPR(3),YNPL(3)
     2,VX(302),VZ(302),AX(302),AZ(302)
      COMMON  JD,JR, NN,NP,NC1,NC2,XX(302,6),ZZ(302,6), ICAL(8),
     1            IFR(302),X(302,8),Z(302,8),ID(12),IR(12),ACC(302),
     2ACCG(302),    CAL(8),XD(302),ZD(302),T(302),DI(302),DC(302)
      COMMON /CPLTC/ HEADL,TITLE(10),IRX,DYLF
      EQUIVALENCE (RES(1),WS(1),DI(1)),(VEL(1),WH(1),DC(1)),(ACC(1),WS2(
     11)),(ACCG(1),WH2(1))
     2,(XX(1,1),VX(1)),(XX(1,2),AX(1)),(ZZ(1,1),VZ(1)),(ZZ(1,2),AZ(1))
      DATA ENDJ/10HEND        /, YNPR/3HYES,3HYES,3H NO/,YNPL/3HYES,3H NO
     1,3H NO/
      DATA HEADR/9H    RANGE,9H     SLED,9H      HIP,9H     KNEE,
     1 9H SHOULDER,9H    ELBOW,9HHEAD PT 1,9HHEAD PT 2/,
     2  HEADL/5HRANGE,4HSLED,3HHIP,4HKNEE,8HSHOULDER,5HELBOW,9HHEAD PT 1
     3, 9HHEAD PT 2/,
     4             HEADC/7H  RANGE,7H   SLED,6H   HIP,7H   KNEE,9H SHOULDE
     5R,7H  ELBOW,9HHEAD PT 1,9HHEAD PT 2/
C*******************************************************************
C*******************************************************************
C       HYGE IMPACT FACILITY PHOTOMETRIC DATA ANALYSIS PROGRAM
C*******************************************************************
C
C                         PARAMETER NAME VERSUS ID CODE
C                                CODE         NAME
C
C                                 1           RANGE
C                                 2           SLED
C                                 3           HIP
C                                 4           KNEE
C                                 5           SHOULDER
C                                 6           ELBOW
C                                 7           HEAD PT 1
C                                 8           HEAD PT 2
C
C*******************************************************************
C*******************************************************************
C
C        IRX=0 --- NO X-AXIS CHANGE
C        IRX=1 --- CHANGE POLARITY OF X-AXIS DATA (MULT.BY -1.0)
C
C        ITYPE=0 - READ AND PROCESS ALL 8 PARAMETER.
C        ITYPE=1 - READ AND PROCESS ONLY PARAMETERS 1, 2, 7 AND 8.
C
C        IPR<1 --- PRINT RAW DATA IN COUNTS
C
C        ICAM=0 -- CAMERA IS NOT ON THE SLED
C        ICAM=1 -- CAMERA IS ON THE SLED; TRANSLATE AND ROTATE DATA.
C
C        IADJ=0 -- NO X OR Z ADJUSTMENT READ OR APPLIED.
C        IADJ=1 -- XADJ AND ZADJ ARE READ AND ADDED TO ALL X AND Z DATA
C                  BEFORE ANY TAB OUTPUT.
C
C        IPL=0 --- PRINT AND PLOT LINEAR VEL AND ACCEL DATA
```

```
C        IPL=1 --- PRINT LINEAR VEL AND ACCEL DATA
C        IPL=2 --- OMIT LINEAR VEL AND ACCEL DATA
C
C        IPA=0 --- PRINT AND PLOT ANGULAR VEL AND ACCEL DATA
C        IPA=1 --- PRINT ANGULAR VEL AND ACCEL DATA
C        IPA=2 --- OMIT  ANGULAR VEL AND ACCEL DATA
C
C        IPC=0 --- PRINT AND PLOT PARAMETER VERSUS SLED DATA
C        IPC=1 --- PRINT PARAMETER VERSUS SLED DATA
C        IPC=2 --- OMIT  PARAMETER VERSUS SLED DATA
C
C        DISPLACEMENT, VEL AND ACCEL DATA ARE COMPUTED FOR THE SETS OF
C        DATA.  ID(I) AND IR(I) CONTAIN THE ** SETS OF PARAMETER CODES
C        FOR PARAMETER AND REFERENCE RESPECTIVELY.
C
C        ID(I) --- CONTAINS PARAMETER IDENT CODE
C        IR(I) --- CONTAINS REFERENCE IDENT CODE
C
C        TITLE(1) --- CONTAINS THE DATE
C        TITLE(2) --- CONTAINS THE TEST NUMBER
C        TITLE(3) ---> TITLE(10) --- CONTAIN AN 80 CHARACTER PAGE TITLE.
C
C        CAL(J) --- CONTAINS THE CALIBRATION FACTORS FOR PARAMETERS 1
C                   THROUGH 8.
C
C        JD --- FRAME NUMBER OF FIRST FRAME PLOTTED ON PARAMETER VERSUS
C               SLED PLOT. (REDEFINED AFTER INPUT)
C        JR --- FRAME NUMBER OF LAST  FRAME PLOTTED ON PARAMETER VERSUS
C               SLED PLOT. (REDEFINED AFTER INPUT)
C
      CALL PLOTS(DATA,1024,7)
C     MAXN IS THE MAXIMUM NUMBER OF FRAMES WHICH CAN BE PROCESSED WITH
C     ABOVE ARRAY DIMENSIONS.
C     MAXN=150
      MAXN=302
      C1=-1.0E10
      CAL(1)=0.0
      ICAL(1)=1
      PI=3.141592
      PI2=2.0*PI
      PI34=3.0*PI/4.0
C     NP IS THE NUMBER OF POINTS USED IN THE QUADRATIC LEAST SQUARE FIT.
C     NP=11
C
C     READ TEST SETUP CARDS.
C     TITLE(1) CONTAINS THE DATE.
C
      READ(5,1010)TITLE(1)
    5 READ(5,1010)(TITLE(I),I=3,10)
      IF (TITLE(3) .EQ. ENDU) GO TO 999
C     READ(5,1005) NP1,NP2,JD,JR
C     IF (NP1 .LT. 3) NP1=11
C     IF (NP2 .LT. 3) NP2=11
C
C     TITLE(2) CONTAINS THE TEST NUMBER.
```

```
C
      READ(5,1030) TITLE(2),IRX,IPR,ITYPE,IPL,ICAM,IPA,IADJ,IPC,JD,JR,M,
     1 (ID(I),IR(I),I=1,12),NP,DYLP
      IF (NP .LT. 3) NP=11
      IF (IADJ .GT. 0) READ(5,1020) XADJ,ZADJ
      READ(5,1020) DT,(CAL(J),J=2,8)
      IF (JD .LT. 1) JD=1
      IF (JR .LT. 1) JR=999
      WRITE(6,2500) TITLE,NP
      IF (IADJ) 440,440,450
  440 IADJ=0
      GO TO 455
  450 IADJ=1
  455 IF (ICAM) 460,460,465
  460 ICAM=0
      GO TO 470
  465 ICAM=1
  470 IF (IRX) 480,480,490
  480 IRX=0
      GO TO 495
  490 IRX=1
  495 IF (IPR) 500,500,505
  500 IPR=0
      GO TO 510
  505 IPR=1
  510 IF (IPL-1) 515,525,520
  515 IPL=0
      GO TO 525
  520 IPL=2
  525 IF (IPA-1) 530,540,535
  530 IPA=0
      GO TO 540
  535 IPA=2
  540 IF (IPC-1) 545,560,550
  545 IPC=0
      GO TO 560
  550 IPC=2
  560 I=1
      IFLAG=0
      NC1=1
      NC2=999
      IFRD=-100
      IF(DT) 565,565,570
  565 DT=500.0
  570 IF (ITYPE) 575,575,580
  575 ITYPE=0
      J1=3
      GO TO 10
  580 ITYPE=1
      J1=7
  585 READ(5,1000) ICD,IFR(I),(X(I,J),Z(I,J),J=1,2),(X(I,J),Z(I,J),J=7,8
     1)
      DO 590 J=3,6
      X(I,J)=0.0
  590 Z(I,J)=0.0
```

```
      IF (ICD-1) 595,595,100
  595 IF (IFR(I)-IFRD) 600,600,610
  600 WRITE(6,2410) IFR(I)
      IFLAG=1
  610 IFRD=IFR(I)
      GO TO 40
C
C  FROM HERE TO LABEL 115: READ A MAXIMUM OF 'MAXN' FRAMES OF INPUT DATA
C
   10 READ(5,1000) ICD,IFR(I),(X(I,J),Z(I,J),J=1,4)
C  FOLLOWING CARD CHANGED TO INPUT PAPER TAPE DATA:
      IF (ICD-1)  15,15,100
C     IF (ICD-1) 100,15,100
   15 IF (IFR(I)-IFRD) 20,20,25
   20 WRITE(6,2410) IFR(I)
      IFLAG=1
   25 READ(5,1000) ICD,IFRD,(X(I,J),Z(I,J),J=5,8)
C  FOLLOWING CARD CHANGED TO INPUT PAPER TAPE DATA:
      IF (ICD-2)  30,30,70
C     IF (ICD-2)  70,30,70
   30 IF (IFR(I)-IFRD) 35,40,35
   35 WRITE(6,2400) IFR(I),IFRD
      IFLAG=1
   40 T(I)=FLOAT(IFR(I))/DT
      IF (IFR(I) .EQ. JD) NC1=I
      IF (IFR(I) .EQ. JR) NC2=I
C  ADD 'XADJ' AND 'ZADJ' TO I-TH DATA POINT:
      IF (IADJ) 55,55,42
   42 DO 45 J=1,2
      X(I,J)=X(I,J)+XADJ
   45 Z(I,J)=Z(I,J)+ZADJ
      DO 50 J=J1,8
      X(I,J)=X(I,J)+XADJ
   50 Z(I,J)=Z(I,J)+ZADJ
   55 IF (I-MAXN) 60,60,65
   60 I=I+1
      IF (ITYPE) 10,10,585
   65 WRITE(6,2840) MAXN,IFR(I)
      IF (ITYPE) 10,10,585
   70 WRITE(6,2000) ICD,IFRD
      IFLAG=1
      GO TO 10
  100 IF (ICD-9) 110,115,110
  110 WRITE(6,2000) ICD,IFR(I)
      IFLAG=1
      IF (ITYPE) 10,10,585
  115 N=I-1
      DTT=(T(N)-T(1))/FLOAT(N-1)
      IF (IRX) 118,118,116
  116 DO 117 I=1,N
      DO 117 J=1,8
  117 X(I,J)=-X(I,J)
C
C  PRINT TEST PARAMETER SUMMARY PAGE.
C
```

```
  115 WRITE(6,2100) (I,I=1,M)
      WRITE(6,2110) TITLE(2),N,DT,IRX,ITYPE,ICAM,IADJ,IPR,IPL,IPA,IPC,M,
     1 (ID(I),IR(I),I=1,M)
      WRITE(6,2120) (HEADL(I),I=2,8)
      WRITE(6,2130) (CAL(I),I=2,8)
      IF (IADJ .GT. 0) WRITE(6,2135) XADJ,ZADJ
      WRITE(6,2140) DIT
      WRITE(6,2150) N
      WRITE(6,2155)  YNPL(2-IRX)
      WRITE(6,2160)  YNPR(IPR+1)
      WRITE(6,2190) YNPR(IPL+1),YNPL(IPL+1)
      WRITE(6,2180) YNPR(IPA+1),YNPL(IPA+1)
      WRITE(6,2170) YNPR(IPC+1),YNPL(IPC+1)
      DO 130 J=2,8
      IF (ABS(CAL(J))) 120,125,120
  120 CAL(J)=1.0/CAL(J)
      ICAL(J)=1
      GO TO 130
  125 ICAL(J)=0
      WRITE(6,2820) HEADL(J)
  130 CONTINUE
      WRITE(6,2570)
      IF (M) 137,137,132
  132 DO 135 K=1,M
      JD=ID(K)
      JR=IR(K)
      IF (ICAL(JD) .LT. 1 .OR. ICAL(JR) .LT. 1) GO TO 135
      WRITE(6,2210) K,HEADL(JD),HEADL(JR)
  135 CONTINUE
  137 IF (IPR) 140,140,165
C
C  PRINT RAW INPUT DATA IN COUNTS.
C
  140 WRITE(6,2500) TITLE,NP
      WRITE(6,2550)
      WRITE(6,2560) HEADC
      DO 145 I=1,N
  145 WRITE(6,2580) IFR(I),(X(I,J),Z(I,J),J=1,8)
      WRITE(6,2500) TITLE,NP
      WRITE(6,2552)
      WRITE(6,2560) HEADC
C
C  COMPUTE AND PRINT FRAME TO FRAME DIFFERENCES IN COUNTS
C
      IF (ITYPE) 148,148,146
  146 DO 147 J=3,6
      XD(J)=C.0
  147 XD(J)=0.0
  148 DO 160 I=2,N
      XD(1)=X(I,1)-X(I-1,1)
      ZD(1)=Z(I,1)-Z(I-1,1)
      XD(2)=X(I,2)-X(I-1,2)-XD(1)
      ZD(2)=Z(I,2)-Z(I-1,2)-ZD(1)
      DO 150 J=J1,8
      XD(J)=X(I,J)-X(I-1,J)-XD(1)
```

```
  150 ZD(J)=Z(I,J)-Z(I-1,J)-ZD(1)
      WRITE(6,2580) IFR(I),(XD(J),ZD(J),J=1,8)
  160 CONTINUE
C  CONVERT DATA FROM COUNTS TO FEET.
  165 IF (IFLAG) 170,170,167
  167 WRITE(6,2500) TITLE,NP
      WRITE(6,2830)
      GO TO 5
  170 IF (ICAM) 175,175,650
  175 DO 185 I=1,N
C
C  H1 AND H2 ADJUST DATA FOR SHIFT IN RANGE REFERENCE READING.
C
      H1=X(I,1)-X(1,1)
      H2=Z(I,1)-Z(1,1)
      X(I,2)=(X(I,2)-H1)*CAL(2)
      Z(I,2)=(Z(I,2)-H2)*CAL(2)
      DO 180 J=J1,8
      X(I,J)=(X(I,J)-H1)*CAL(J)
  180 Z(I,J)=(Z(I,J)-H2)*CAL(J)
  185 CONTINUE
C     DO 800 NP=NP1,NP2,2
      GO TO 695
  650 IF (IPR) 655,655,660
  655 WRITE(6,2500) TITLE,NP
      WRITE(6,2540)
      WRITE(6,2560) HEADC
C  CALL SUBROUTINE 'ROTATE' TO ROTATE, TRANSLATE, AND CALIBRATE THE
C  ON-BOARD CAMERA DATA (ICAM>0).
  660 CALL ROTATE(N,J1,IPR)
C  COMPUTE THE MEAN AND STANDARD DEVIATION ABOUT THE MEAN FOR SLED
C  REFERENCE DATA:
  695 CALL MEAN1(N,X(1,2),Z(1,2))
      N1=(NP-1)/2+1
      N2=N-N1+1
      N3=3*N1-2
      N4=N-N3+1
      NN=N2-N1+1
      IF (IPC+IPA-4) 700,800,800
C
C*********** COMPUTE PARAMETER VERSUS SLED DISPLACEMENTS.
C
  700 DO 725 J=3,8
      JJ=J-2
      IF (ICAL(J)) 715,715,705
  705 DO 710 I=1,N
      XD(I)=X(I,J)-X(I,2)
  710 ZD(I)=Z(I,J)-Z(I,2)
      I=1
      CALL SM(T,XD,XX(I,JJ),N,NP)
      CALL SM(T,ZD,ZZ(I,JJ),N,NP)
      GO TO 725
  715 DO 720 I=N1,N2
      XX(I,JJ)=0.0
  720 ZZ(I,JJ)=0.0
```

```
  725 CONTINUE
      IF (IPC-1) 728,728,743
  728 LINE=60
      DO 740 I=N1,N2
      IF (LINE-50) 735,730,730
  730 WRITE(6,2500) TITLE,NP
      WRITE(6,2555)
      WRITE(6,2565)    (HEADC(J),J=3,8)
      LINE= 0
C  PRINT PARAMETER VERSUS SLED DATA.
  735 WRITE(6,2585) IFR(I),T(I),(XX(I,JJ),ZZ(I,JJ),JJ=1,6)
      LINE=LINE+1
  740 CONTINUE
      IF (IPC) 742,742,743
  742 IF (NC1 .LT. N1) NC1=N1
      IF (NC2 .GT. N2) NC2=N2
      NN=NC2-NC1+1
      IP=1
C  PLOT PARAMETER VERSUS SLED DATA.
      CALL CPLT(T,DI,DC,IP)
      WRITE(6,2595) IFR(NC1),IFR(NC2)
  743 IF (IPA-2) 745,800,800
C************************
C  COMPUTE ANGULAR VELOCITY AND ACCELERATION;  HERE TO LABEL 775.
C************************
  745 XD(N1-1)=PI
      ZD(N1-1)=PI
      IF (ICAL(3)+ICAL(5)-2) 756,750,750
  750 DO 755 I=N1,N2
      H1=ZZ(I,3)-ZZ(I,1)
      H2=XX(I,3)-XX(I,1)
C  SHOULDER - HIP ANGLE
      XD(I)=ATAN2(H1,H2)
      IF (XD(I) .LT. 0.0) XD(I)=XD(I)+PI2
      IF (ABS(XD(I)-XD(I-1)) .GT. PI34) XD(I)=XD(I)+PI2
  755 CONTINUE
      CALL DERIV1(T,XD,WS,N,NP,1)
      CALL DERIV1(T,WS,WS2,N,NP,2)
      GO TO 758
  756 DO 757 I=N1,N2
      XD(I)=0.0
      WS(I)=0.0
  757 WS2(I)=0.0
  758 IF (ICAL(7)+ICAL(8)-2) 762,759,759
  759 DO 760 I=N1,N2
      H1=ZZ(I,5)-ZZ(I,6)
      H2=XX(I,5)-XX(I,6)
C  HEAD PT 1 - HEAD PT 2 ANGLE!
      ZD(I)=ATAN2(H1,H2)
      IF (ZD(I) .LT. 0.0) ZD(I)=ZD(I)+PI2
      IF (ABS(ZD(I)-ZD(I-1)) .GT. PI34) ZD(I)=ZD(I)+PI2
  760 CONTINUE
      CALL DERIV1(T,ZD,WH,N,NP,1)
      CALL DERIV1(T,WH,WH2,N,NP,2)
      GO TO 763
```

```
  762 DO 764 I=N1,N2
      ZD(I)=0.0
      WH(I)=0.0
  764 WH2(I)=0.0
  768 LINE=60
      DO 775 I=N3,N4
      IF (LINE-50) 772,770,770
  770 WRITE(6,2500) TITLE,NP
      WRITE(6,2551)
      WRITE(6,2520)
      LINE= 0
C  PRINT   ANGULAR VELOCITY AND ACCELERATION.
  772 WRITE(6,2590) IFR(I),T(I),XD(I),WS(I),WS2(I),ZD(I),WH(I),WH2(I)
      LINE=LINE+1
  775 CONTINUE
      IF (IPA) 780,780,800
  780 IP=2
      NN=N4-N3+1
      JD=5
      JR=3
      IF (ICAL(3)+ICAL(5)-2) 790,785,785
C  PLOT ANGULAR VELOCITY AND ACCELERATION DATA.
  785 CALL CPLT(T(N3),WS(N3),WS2(N3),IP)
  790 JD=7
      JR=8
      IF (ICAL(7)+ICAL(8)-2) 800,795,795
  795 CALL CPLT(T(N3),WH(N3),WH2(N3),IP)
  800 CONTINUE
      IF (M .LT. 1 .OR. IPL .EQ. 2) GO TO 5
      DO 200 J=2,8
      IF (ICAL(J)) 200,200,190
  190 DO 195 I=2,N
      X(I,J)= X(I,J)-X(1,J)
  195 Z(I,J)= Z(I,J)-Z(1,J)
      X(1,J)= 0.0
      Z(1,J)= 0.0
  200 CONTINUE
      IP=3
C 202 DO 410 NP=NP1,NP2,2
C     N1=(NP-1)/2+1
C     N2=N-N1+1
C     N3=3*N1-2
C     N4=N-N3+1
      NN=N4-N3+1
C
C************************
C  COMPUTE LINEAR VELOCITY AND ACCEL DATA FOR PARAMETER ID(K) WITH
C  RESPECT TO IR(K); HERE TO LABEL 400.
C************************
C
      DO 400 K=1,M
      JD=ID(K)
      IF (JD .LE. 1) GO TO 390
      JR=IR(K)
      IF (JR .LT. 1) GO TO 395
```

```
      IF (ICAL(JD) .LT. 1 .OR. ICAL(JR) .LT. 1) GO TO 400
      XMP=C1
      ZMP=C1
      RM= C1
      XMN=-C1
      ZMN=-C1
      DO 212 I=1,N
      IF (JR-1) 205,205,210
  205 DI(I)=X(I,JD)
      DC(I)=Z(I,JD)
      GO TO 212
  210 DI(I)=X(I,JD)-X(I,JR)
      DC(I)=Z(I,JD)-Z(I,JR)
  212 CONTINUE
      CALL SM(T,DI,XD,N,NP)
      CALL SM(T,DC,ZD,N,NP)
C  COMPUTE MEAN AND STANDARD DEVIATION OF DIFFERENCE BETWEEN SMOOTHED
C  AND UNSMOOTHED DISPLACEMENT DATA:
      CALL MEAN2(N1,N2,DI,DC,XD,ZD,SMX,SMX2,SMZ,SMZ2)
C
C  COMPUTE MAXIMUM X, Z AND RESULTANT DISPLACEMENT.
C
      DO 260 I=N1,N2
      RES(I)=SQRT(XD(I)*XD(I)+ZD(I)*ZD(I))
      IF (XD(I)-XMP) 220,220,215
  215 XMP=XD(I)
      TXMP=T(I)
      GO TO 230
  220 IF (XD(I)-XMN) 225,230,230
  225 XMN=XD(I)
      TXMN=T(I)
  230 IF (ZD(I)-ZMP) 240,240,235
  235 ZMP=ZD(I)
      TZMP=T(I)
      GO TO 250
  240 IF (ZD(I)-ZMN) 245,245,250
  245 ZMN=ZD(I)
      TZMN=T(I)
  250 IF (RES(I)-RM) 260,260,255
  255 RM=RES(I)
      TRM= T(I)
  260 CONTINUE
C  COMPUTE LINEAR VELOCITY.
      CALL DERIV1(T,XD,VX,N,NP,1)
      CALL DERIV1(T,ZD,VZ,N,NP,1)
C  COMPUTE LINEAR ACCELERATION DATA.
      CALL DERIV1(T,VX,AX,N,NP,2)
      CALL DERIV1(T,VZ,AZ,N,NP,2)
      LINE=60
      DO 280 I=N3,N4
      VEL(I)=SQRT(VX(I)*VX(I)+VZ(I)*VZ(I))
      ACC(I)=SQRT(AX(I)*AX(I)+AZ(I)*AZ(I))
      IF (LINE-50) 275,270,270
  270 WRITE(6,2500) TITLE,NP
      WRITE(6,2200) HEADR(JD),HEADL(JR)
```

```
      WRITE(6,2510)
      LINE= 0
C  PRINT LINEAR DISPL, VEL AND ACCEL DATA.
  275 ACCG(I)=ACC(I)/32.2
      WRITE(6,2600) IFR(I),T(I),XD(I),ZD(I),RES(I),VEL(I),ACC(I),ACCG(I)
      LINE=LINE+1
  280 CONTINUE
      IF (LINE-40)  330,330,320
  320 WRITE(6,2500) TITLE,NP
      WRITE(6,2200) HEADR(JD),HEADL(JR)
  330 WRITE(6,2700) XMP,TXMP
      WRITE(6,2710) XMN,TXMN
      WRITE(6,2720)ZMP,TZMP
      WRITE(6,2730) ZMN,TZMN
      WRITE(6,2740) RM,TRM
      WRITE(6,2920) SMX,SMX2,SMZ,SMZ2
C
C  PLOT LINEAR VELOCITY AND ACCELERATION DATA.
C
  350 IF (IPL) 360,360,400
  360 CALL CPLT(T(N3),VEL(N3),ACCG(N3),IP)
      GO TO 400
  390 WRITE(6,2500) TITLE,NP
      WRITE(6,2800) K
      GO TO 400
  395 WRITE(6,2500) TITLE,NP
      WRITE(6,2810) K
  400 CONTINUE
C 410 CONTINUE
      GO TO 5
  999 WRITE(6,2900)
      CALL PLOTE
      STOP
C  FOLLOWING CARD CHANGED TO INPUT PAPER TAPE DATA:
 1000 FORMAT(I1,I4,8F7.0)
C1000 FORMAT(I1,I5,8F6.0)
 1010 FORMAT(8A10)
 1020 FORMAT(8F10.0)
 1030 FORMAT(A5,8I1,    2I3,I2,12(I2,I1),I3,F5.0)
 2000 FORMAT(/ 4X,*ERROR IN CARD IDENTIFICATION NUMBER; CARD ID=*,I2,
     1 *; FRAME NUMBER =*,I4)
 2100 FORMAT(// 4X,*TEST     N       DT      IRX  ITYPE  ICAM  IADJ  IPR
     1IPL   IPA   IPC   M  SETS:*,12I4)
 2110 FORMAT( 3X,A5,I6,F10.3,I4,7I6,I5,7X,12(I3,I1))
 2120 FORMAT(// 36X,7(A10,2X))
 2130 FORMAT(  4X,*CALIB DATA IN COUNTS PER FOOT:*,F9.3,6F12.3)
 2135 FORMAT(/ 4X,*ADJUSTMENT FACTORS ADDED TO ALL X AND Z INPUT DATA: X
     1ADJ=*,F10.2,* AND ZADJ=*,F10.2)
 2140 FORMAT(/ 4X,*AVERAGE TIME INCREMENT BETWEEN POINTS:*,F10.5)
 2150 FORMAT(/4X,*NUMBER OF FRAMES READ: *,I4,* FRAMES*)
 2155 FORMAT(/4X,*REVERSE POLARITY OF X-AXIS DATA (MULT. BY -1.0): *,A3)
 2160 FORMAT(/4X,*PRINT LISTING OF INPUT DATA IN COUNTS:  *,A3)
 2170 FORMAT(/4X,*PARAMETERS RELATIVE TO SLED DISPLACEMENTS:    PRINT? *,
     1A3,4X,*PLOT? *,A3)
 2180 FORMAT(/4X,*ANGULAR VELOCITY  AND  ACCELERATION DATA:    PRINT? *,
```

```
   1A3,4X,*PLOT? *,A3)
2190 FORMAT(/4X,*LINEAR  VELOCITY  AND  ACCELERATION DATA:    PRINT? *,
   1A3,4X,*PLOT? *,A3)
2200 FORMAT(// 31X,A9,* MOTION RELATIVE TO THE *,A9
2210 FORMAT(/10X,I2,*) *,A9,* MOTION RELATIVE TO THE *,A9)
2400 FORMAT(/ 4X,*ERROR IN FRAME NUMBERS; FRAME NUMBER ON CARD 1 =*,I4,
   1 * FRAME NUMBER ON CARD 2 =*,I4)
2410 FORMAT(/ 4X,*FRAME NUMBER IS NOT INCREASING; CHECK FRAME COUNT FOR
   1 CARD 1, FRAME= *,I5)
2500 FORMAT(1H1,3X,*DATE: *,A10,20X,*TEST NUMBER: *,A5/
   1/ 4X,8A10,5X,I2,* POINT QUADRATIC FIT*)
2510 FORMAT(/  32X,*DISPLACEMENT*,15X,*VELOCITY *,2(5X,*ACCELERATION*)/
   A  4X,*FRAME*,
   1   4X,*TIME*,8X,*X*,10X,*Z  *,2(5X,*RESULTANT*),2(8X,*RESULTANT*)/
   B  4X,* NO. *,
   2  4X,*(SEC)*,2(5X,*(FEET)*),6X,*(FEET)*,7X,*(FT/SEC)*,7X,*(FT/SEC
   3SQ)*,10X,*(G)*)
2520 FORMAT(// 29X,*SHOULDER - HIP*,21X,*HEAD PT 1 - HEAD PT 2*/
   1  * FRAME     TIME*, 2( 7X,*THETA*, 8X,*W*,10X,*W-ACC*, 4X)/
   2  *  NO.      (SEC)*, 2(4X,*(RADIANS)  (RAD/SEC)  (RAD/SEC SQ) *))
2540 FORMAT(//4X,*THE FOLLOWING IS A LISTING OF THE INPUT DATA IN COUNT
   1S AFTER TRANSLATION AND ROTATION OF ON-BOARD CAMERA DATA:*)
2550 FORMAT(//4X,*THE FOLLOWING IS A LISTING OF THE INPUT DATA IN COUNT
   1S:*)
2551 FORMAT(//4X,*THE FOLLOWING IS A LISTING OF THE ANGULAR MOTION OF T
   1HE HEAD AND SHOULDER:*)
2552 FORMAT(//4X,*THE FOLLOWING IS A LISTING OF D(I)-DR(I)-D(I-1)+DR(I-
   11) IN COUNTS:*)
2555 FORMAT(//4X,*THE FOLLOWING IS A LISTING OF PARAMETER - SLED DISPLA
   1CEMENT IN FEET:*)
2560 FORMAT(//    * FRAME *, 8(6X,A10)/  2X,*NO.*, 8(8X,*X*,6X,*Z*))
2565 FORMAT(//    * FRAME      TIME *,6( 7X,A10)/
   1    *  NO.      (SEC)*, 6( 7X,*X*,6X,*Z  *))
2570 FORMAT(//4X,*LINEAR DISPLACEMENT, VELOCITY AND ACCELERATION DATA W
   1ILL BE COMPUTED FOR THE FOLLOWING:*)
2580 FORMAT(1X,I4,2X,8(F9.0,F7.0))
2585 FORMAT(1X,I4,F11.5,6(F10.3,F7.3))
2590 FORMAT(1X,I4,F11.5,2(F10.3,F11.3,F13.3,6X))
2595 FORMAT(//4X,*THE ABOVE DATA WAS PLOTTED (X VERSUS Z) FOR FRAME NUM
   1BER*,I4,* TO FRAME NUMBER*,I4)
2600 FORMAT(4X,I4, F11.5,F10.3,F11.3,F12.3,F15.3,F16.3,F17.3)
2700 FORMAT(/  4X,*MAXIMUM POSITIVE X DISPLACEMENT=*,F8.3,  * AT TIME *
   1, F8.5)
2710 FORMAT(/  4X,*MAXIMUM NEGATIVE X DISPLACEMENT=*,F8.3,  * AT TIME *
   1, F8.5)
2720 FORMAT(/  4X,*MAXIMUM POSITIVE Z DISPLACEMENT=*,F8.3,  * AT TIME *
   1, F8.5)
2730 FORMAT(/  4X,*MAXIMUM NEGATIVE Z DISPLACEMENT=*,F8.3,  * AT TIME *
   1, F8.5)
2740 FORMAT(/  4X,*MAXIMUM RESULTANT  DISPLACEMENT=*,F8.3,  * AT TIME *
   1, F8.5)
2800 FORMAT(///4X,  *OMIT COMPUTATIONS FOR SET*,I3/  4X,*THE PROGRAM IS
   1 NOT DESIGNED TO COMPUTE RANGE DISPLACEMENT, VELOCITY AND ACCELERA
   2TION.*/  4X,*DATA PARAMETER CODE IS LESS THAN OR EQUAL TO 1*)
2810 FORMAT(///4X,  *OMIT COMPUTATIONS FOR SET*,I3/
```

```
     1    4X,*REFERENCE PARAMETER CODE IS LESS THAN 1*)
2820 FORMAT(/ 4X,*CALIBRATION FACTOR IS 0.0 THUS COMPUTATIONS WILL BE O
     1MITTED FOR THE FOLLOWING PARAMETER: *,A10)
2830 FORMAT(//1X,134(1H*)//4X,  *OMIT THE REMAINDER OF THE COMPUTATIONS
     1 FOR THIS TEST BECAUSE OF INPUT CARD PROBLEMS.*/
     2 4X,*SEE ERROR STATEMENTS AT THE BEGINNING OF THE OUTPUT FOR THIS
     3TEST*// 1X,134(1H*))
2840 FORMAT(/4X,*NUMBER OF FRAMES IS >*,I4,*;  OMIT DATA FOR FRAME NUMB
     1ER:*,I4)
2900 FORMAT(*1  END OF JOB*)
2920 FORMAT(/4X,*MEAN AND STANDARD DEVIATION OF UNSMOOTHED-SMOOTHED DIS
     1PLACEMENT DATA:*/4X,*MEAN AND S.D. OF X=*,1P2E15.5/4X,*MEAN AND S.
     2D. OF Z=*, 2E15.5)
      END
```

```
      SUBROUTINE CPLT(T,Y,Z,IP)
      DIMENSION X(302),T(1),Y(1),Z(1)
      COMMON  JD,JR,  N,NP,I1,I2,XX(302,6),ZZ(302,6),ICAL(8)
      COMMON /CPLTC/ HEADL(8),DATE,TEST,TITLE(8),IRX,DYLP
C   IP=1 --- COMPOSITE PLOT OF PARAMETER VERSUS SLED DATA
C   IP=2 --- PLOT OF ANGULAR VEL AND ACCEL
C   IP=3 --- PLOT OF VEL AND ACCEL
C   SXMAX IS THE MAXIMUM LENGTH OF THE TIME SCALE IN INCHES.
C     SXMAX=17.0
      SXMAX=32.0
      SY=10.0
      DX=0.02
      N1=N+1
      N2=N+2
      IF (IP-2) 300,5,5
    5 DO  10 J=1,N
   10 X(J)=T(J)
      X(N1)=FLOAT(IFIX(X(1)*100.01))*0.01
      X(N2)=DX
      SX=   FLOAT(IFIX((X(N)-X(N1))/DX)+1)
      IF (SX .GT. SXMAX) SX= SXMAX
      CALL AXIS(0.0,0.0,12HTIME IN SEC.,-12,SX,0.0,X(N1),DX)
      IF (IP .EQ. 2) GO TO 400
      AMX=-1.0E10
      AMN= 1.0E10
      DO  15 J=1,N
      AMX=AMAX1(AMX,Y(J))
      AMX=AMAX1(AMX,Z(J))
      AMN=AMIN1(AMN,Y(J))
      AMN=AMIN1(AMN,Z(J))
   15 CONTINUE
      IF (AMN) 30,20,20
   20 AMN=0.0
      GO TO 40
   30 AMN=FLOAT(IFIX(AMN/2.5)-1)*2.5
   40 AMX=FLOAT(IFIX(AMX/2.5)+1)*2.5
      IF (DYLP) 43,43,42
   42 DY=DYLP
      GO TO 90
   43 DYY=(AMX-AMN)/SY
      IF (DYY-2.5) 44,44,45
   44 DY=2.5
      YMIN=AMN
      GO TO 100
   45 IF (DYY-5.0) 46,46,48
   46 DY=5.0
      GO TO 90
   48 IF (DYY-10.0) 50,50,60
   50 DY=10.0
      GO TO 90
   60 IF (DYY-20.0) 70,70,80
   70 DY=20.0
      GO TO 90
   80 DY=30.0
   90 YMIN=FLOAT(IFIX(AMN/DY)   )*DY
```

```
      IF (YMIN .GT. AMN) YMIN=YMIN-DY
      IF (YMIN .GT. AMN) YMIN=YMIN-DY
  100 YMAX=SY*DY+YMIN
      IF (AMX .LE. YMAX) GO TO 102
      YMIN=YMIN+DY
      YMAX=YMAX+DY
  102 Y(N1)=YMIN
      Z(N1)=YMIN
      Y(N2)=DY
      Z(N2)=DY
      CALL AXIS(0.0,0.0,26HVEL IN FT/SEC --- ACC IN G,26,SY,90.,YMIN,DY)
      IF (YMIN) 105,110,110
  105 Y0=ABS(YMIN/DY)
      CALL PLOT(0.0,Y0,3)
      CALL PLOT(SX, Y0,2)
  110 DO 120 I=1,N
      IF (Y(I) .GT. YMAX) Y(I)=YMAX
      IF (Z(I) .GT. YMAX) Z(I)=YMAX
      IF (Y(I) .LT. YMIN) Y(I)=YMIN
      IF (Z(I) .LT. YMIN) Z(I)=YMIN
  120 CONTINUE
  130 CALL LINE(X,Y,N,1,10,1)
      CALL LINE(X,Z,N,1,10,3)
      H1=HEADL(JD)
      CALL SYMBOL(0.25,9.5,0.105,H1,0.0,8)
      CALL SYMBOL(0.25,9.3,0.105,6HREL TO,0.0,6)
      H1=HEADL(JR)
      CALL SYMBOL(0.25,9.1,0.105,H1,0.0,8)
      J=1
      CALL SYMBOL(0.5, 8.8,0.105,J,0.0,-1)
      CALL SYMBOL(0.65,8.75,0.105,3HVEL,0.0,3)
      J=3
      CALL SYMBOL(0.5, 8.55,0.105,J,0.0,-1)
      CALL SYMBOL(0.65,8.50,0.105,3HACC,0.0,3)
  140 CALL SYMBOL(0.25,9.8,0.105,4HTEST,0.0,4)
      CALL SYMBOL(0.75,9.8,0.105,TEST,0.0,5)
      CALL NUMBER(1.75,9.8,0.105,FLOAT(NP),0.0,-1)
      CALL SYMBOL(2.05,9.8,0.105,9HPOINT FIT,0.0,9)
      GO TO 999
C
C  PLOT THE COMPOSITE PLOT OF PARAMETERS VERSUS SLED.
C  NOTE:  ORDINATE AND ABSCISSA SCALING IS FIXED.
C
  300 ZMIN=0.0
C     XMIN=-1.4-2.2*FLOAT(IRX)
      XMIN=-1.0
      DZ=0.4
      DX=0.4
      SX=10.0
      CALL AXIS(0.0,0.0,14HX DISP IN FEET,-14,SX,0.0,XMIN,DX)
      CALL AXIS(0.0,0.0,14HZ DISP IN FEET, 14,SY,90.0,ZMIN,DZ)
      CALL SYMBOL(0.25,9.5,0.105,16HDATA REL TO SLED,0.0,16)
      X(N1)=XMIN
      X(N2)=DX
      Z(N1)=ZMIN
```

```
      Z(N2)=DZ
      XMAX=SX*DX+XMIN
      ZMAX=SY*DZ+ZMIN
      Y0=10.0
      DO 310 J=1,6
      IF (ICAL(J+2)) 310,310,305
  305 H1=HEADL(J+2)
      Y0=Y0-0.25
      CALL SYMBOL(-1.75,Y0+0.05,0.105,J,0.0,-1)
      CALL SYMBOL(-1.60,Y0,0.105,H1,0.0,9)
  310 CONTINUE
      DO 325 J=1,6
      IF (ICAL(J+2)) 325,325,315
  315 II=0
      DO 320 I=I1,I2
      II=II+1
      X(II)=XX(I,J)
      Z(II)=ZZ(I,J)
      IF (X(II) .GT. XMAX) X(II)=XMAX
      IF (X(II) .LT. XMIN) X(II)=XMIN
      IF (Z(II) .GT. ZMAX) Z(II)=ZMAX
      IF (Z(II) .LT. ZMIN) Z(II)=ZMIN
  320 CONTINUE
      CALL LINE(X,Z,N,1,-1,J)
  325 CONTINUE
      GO TO 140
C
C  SETUP AND PLOT ANGULAR VEL AND ACCEL.
C
  400 CALL SCALE(Y,SY,N,1)
      CALL SCALE(Z,SY,N,1)
      YMIN=Y(N1)
      ZMIN=Z(N1)
      DY=  Y(N2)
      DZ=  Z(N2)
      WRITE(6,2000) YMIN,DY,ZMIN,DZ
      CALL AXIS(0.0,0.0,22HANGULAR VEL -- RAD/SEC,     22,SY,90.,YMIN,DY)
      CALL AXIS(SX,0.0,26HANGULAR ACC -- RAD/SEC/SEC,-26,SY,90.,ZMIN,DZ)
      GO TO 130
  999 CALL PLOT(SX+3.0,0.0,-3)
      RETURN
 2000 FORMAT(//4X,*THE ABOVE VEL AND ACCEL DATA ARE PLOTTED:  YMIN=*,
     1F10.2,*   DY=*,F8.2 ,5X,* ZMIN=*,F10.2,*   DZ=*,F8.2)
      END
```

```
      SUBROUTINE SM(X,Y,YC,N,NP)
C  NP MUST BE AN ODD INTEGER .GE. 3.
C  COMPUTE THE COEFFICIENTS FOR A QUADRATIC LEAST SQUARES FIT OF 'NP'
C  POINTS AND COMPUTE THE FIT OF THE DATA (NO DERIVATIVES) 'YC(I)'.
      DIMENSION C(3),X(1),Y(1),YC(1)
      M=(NP-1)/2
      NN=N-M
      N1=NN+1
      DO 10 I=1,M
   10 YC(I)=0.0
      DO 20 I=N1,N
   20 YC(I)=0.0
      MM=M+1
      DO 100 I=MM,NN
      N1=I-M
      N2=I+M
      CALL QLSQ(X,Y,N1,N2,C)
      YC(I)=C(1)*X(I)*X(I)+C(2)*X(I)+C(3)
C     YP(I)=2.0*C(1)*X(I)+C(2)
C     YPP(I)=2.0*C(1)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DERIV1(X,Y,YP,N,NP,ID)
C   NP MUST BE AN ODD INTEGER .GE. 3.
C   ID=1 FOR FIRST DERIVATIVE.
C   ID=2 FOR SECOND DERIVATIVE.
C   COMPUTE THE COEFFICIENTS FOR A QUADRATIC LEAST SQUARES FIT OF 'NP'
C   POINTS AND COMPUTE THE FIRST DERIVATIVE 'YP(I)'.
      DIMENSION C(3),X(1),Y(1),YP(1)
      M=(NP-1)/2
      K=M+M*ID
      NN=N-K
      N1=NN+1
      DO 10 I=1,K
   10 YP(I)=0.0
      DO 20 I=N1,N
   20 YP(I)=0.0
      MM=K+1
      DO 100 I=MM,NN
      N1=I-M
      N2=I+M
      CALL QLSQ(X,Y,N1,N2,C)
      YP(I)=2.0*C(1)*X(I)+C(2)
C     YC(I)=C(1)*X(I)*X(I)+C(2)*X(I)+C(3)
C     YPP(I)=2.0*C(1)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE QLSQ(X,Y,N1,N2,C)
      DIMENSION X(1),Y(1),C(1)
C
C   THIS SUBROUTINE COMPUTES THE QUADRATIC LEAST SQUARE COEFFICIENTS
C   'C(3)' FOR NP DATA POINTS (NP MUST BE AN ODD INTEGER .GE. 3).
C   THE DATA NEED NOT BE EQUALLY SPACED.
C      C(1)*(X**2)+C(2)*X+C(3)=Y
C      C(1)*X+C(2)=Y
C   SUBSTITUTE XP=X-FF,  WHERE FF IS X((N1+N2)/2)
C   THEN C(3)=C(3)+C(1)*FF*FF-C(2)*FF
C          C(2)=C(2)-2.0*C(1)*FF
C          C(1)=C(1)
C
      F(A1,A2,A3,B1,B2,B3,C1,C2,C3)=A1*(B2*C3-B3*C2)+A2*(B3*C1-B1*C3)+A3
     1*(B1*C2-B2*C1)
      FN=FLOAT(N2-N1+1)
      NN=(N1+N2)/2
      FF=X(NN)
      Z1=0
      Z2=0
      Z3=0
      Z4=0
      Z5=0
      Z6=0
      Z7=0
   10 DO 20 I=N1,N2
      X2=X(I)-FF
      X1=X2*X2
      Z1=Z1+X2
      Z2=Z2+X1
      Z3=Z3+X1*X2
      Z4=Z4+X1*X1
      Z5=Z5+Y(I)
      Z6=Z6+X2*Y(I)
      Z7=Z7+X1*Y(I)
   20 CONTINUE
      DEN=F(Z4,Z3,Z2,Z3,Z2,Z1,Z2,Z1,FN)
      C(1)=F(Z7,Z6,Z5,Z3,Z2,Z1,Z2,Z1,FN)/DEN
      C(2)=F(Z4,Z3,Z2,Z7,Z6,Z5,Z2,Z1,FN)/DEN
      C(3)=F(Z4,Z3,Z2,Z3,Z2,Z1,Z7,Z6,Z5)/DEN
      C(3)=C(3)+C(1)*FF*FF-C(2)*FF
      C(2)=C(2)-2.0*C(1)*FF
      RETURN
      END
```

```
      SUBROUTINE ROTATE(N,J1,IPR)
      COMMON  JO,JR, NN,NP,NC1,NC2,XX(302,6),ZZ(302,6), ICAL(8),
     1          IFR(302),X(302,8),Z(302,8),ID(12),IR(12),ACC(302),
     2ACCS(302),    CAL(8),XD(302),ZD(302)
C   THIS SUBROUTINE TRANSLATES, ROTATES, AND CALIBRATES THE ON-BOARD
C   CAMERA DATA STORED IN THE 'X' AND 'Z' ARRAYS.  ALL DATA ARE
C   TRANSLATED TO A COORDINATE SYSTEM THROUGH THE SLED RANGE REFERENCE
C   POINT (FIRST X,Z PAIR FOR EACH TIME).
C   AXIS IS THEN ROTATED SO THE ANGLE BETWEEN THE SLED RANGE REFERENCE
C   AND THE SLED REFERENCE (SECOND X,Z PAIR FOR EACH TIME) IS THE SAME
C   FOR ALL TIME STATIONS (SAME AS AT TIME 0).
C   FIRST POINT IS RANGE REFERENCE ON THE SLED.
C   SECOND POINT IS THE SLED REFERENCE POINT.
      PI2=6.283185308
      I=1
      XR=X(I,1)
      ZR=Z(I,1)
      IF (IPR) 10,10,15
   10 WRITE(6,2580) IFR(I),(X(I,J),Z(I,J),J=1,8)
C   SUBTRACT INITIAL RANGE VALUE FROM SLED REFERENCE AND DETERMINE THE
C   REFERENCE ANGLE.
   15 X1=X(I,2)-XR
      Z1=Z(I,2)-ZR
      X(I,2)=X(I,2)*CAL(2)
      Z(I,2)=Z(I,2)*CAL(2)
      DO 20 J=J1,8
      X(I,J)=X(I,J)*CAL(J)
   20 Z(I,J)=Z(I,J)*CAL(J)
C   'THR' IS THE REFERENCE ANGLE BETWEEN THE TWO REFERENCE POINTS ON THE
C   SLED FOR THE FIRST TIME STATION (RANGE AND SLED REFERENCE POINTS):
C   ALL DATA FOR I=2 TO N ARE ROTATED TO MAKE THE ANGLE BETWEEN THE TWO
C   POINTS THE SAME.
   35 THR=ATAN2(Z1,X1)
      IF (THR .LT. 0.0) THR=THR+PI2
      DO 50 I=2,N
      H1=X(I,1)
      H2=Z(I,1)
C   TRANSLATE SLED REFERENCE DATA TO COORDINATE SYSTEM THROUGH SLED RANGE
C   REFERENCE AND DETERMINE THE ANGLE BETWEEN SLED RANGE REFERENCE AND
C   THE SLED REFERENCE POINTS (FOR I-TH TIME STATION).
      X1=X(I,2)-H1
      Z1=Z(I,2)-H2
      THI=ATAN2(Z1,X1)
      IF (THI .LT. 0.0) THI=THI+PI2
C   ALL DATA ARE ROTATED BY ANGLE TH=THI-THR.
      TH=THI-THR
      CS=COS(TH)
      SN=SIN(TH)
C   ROTATE SLED REFERENCE AND TRANSLATE BACK TO INITIAL COORDINATE SYSTEM
      XD(2)=X1*CS+Z1*SN+XR
      ZD(2)=-X1*SN+Z1*CS+ZR
      X(I,2)=XD(2)*CAL(2)
      Z(I,2)=ZD(2)*CAL(2)
      DO 40 J=J1,8
C   TRANSLATE BY  1 AND H2 AND ROTATE BY ANGLE 'TH' THEN TRANSLATE BACK
```

```
C   TO INITIAL COORDINATE SYSTEM.
      X1=X(I,J)-H1
      Z1=Z(I,J)-H2
      XD(J)=X1*CS+Z1*SN+XR
      ZD(J)=-X1*SN+Z1*CS+ZR
      X(I,J)=XD(J)*CAL(J)
   40 Z(I,J)=ZD(J)*CAL(J)
      X(I,1)=XR
      Z(I,1)=ZR
      IF (IPR) 45,45,50
   45 WRITE(6,2580) IFR(I),X(I,1),Z(I,1),(XD(J),ZD(J),J=2,8)
   50 CONTINUE
 2580 FORMAT(1X,I4,2X,8(F9.0,F7.0))
      RETURN
      END
```

```
      SUBROUTINE MEAN1(N,X,Z)
C     COMPUTE MEAN AND S.D. ABOUT THE MEAN FOR SLED REFERENCE DATA
      DIMENSION X(1),Z(1)
      SMX=SMZ=0.0
      DO 50 I=1,N
      SMX=SMX+X(I)
   50 SMZ=SMZ+Z(I)
      AVX=SMX/FLOAT(N)
      AVZ=SMZ/FLOAT(N)
      SMX=SMZ=0.0
      DO 100 I=1,N
      SMX=SMX+(X(I)-AVX)**2
  100 SMZ=SMZ+(Z(I)-AVZ)**2
      SMX=SQRT(SMX/FLOAT(N-1))
      SMZ=SQRT(SMZ/FLOAT(N-1))
      WRITE(6,2000) AVX,SMX,AVZ,SMZ
 2000 FORMAT(*1   MEAN AND STANDARD DEVIATION ABOUT THE MEAN OF THE SLED
     1 REFERENCE DATA IN FEET:*/4X,*MEAN AND S.D. OF X=*,1P2E15.5/4X,
     2 *MEAN AND S.D. OF Z=*,2E15.5)
      RETURN
      END
```

```
      SUBROUTINE MEAN2(N1,N2,DI,DC,XD,ZD,SMX,SMX2,SMZ,SMZ2)               018960
      DIMENSION DI(1),DC(1),XD(1),ZD(1)                                   018980
C     COMPUTE AVERAGE AND S.D. OF UNSMOOTHED MINUS SMOOTHED DATA:         019000
      FNN=FLOAT(N2-N1+1)                                                  019020
      SMX=SMX2=SMZ=SMZ2=0.0                                               019040
      DO 100 I=N1,N2                                                      019060
      DIFX=DI(I)-XD(I)                                                    019080
      DIFZ=DC(I)-ZD(I)                                                    019100
      SMX=SMX+DIFX                                                        019120
      SMZ=SMZ+DIFZ                                                        019140
      SMX2=SMX2+DIFX**2                                                   019160
  100 SMZ2=SMZ2+DIFZ**2                                                   019180
      SMX=SMX/FNN                                                         019200
      SMZ=SMZ/FNN                                                         019220
      SMX2=SQRT((SMX2-SMX*SMX*FNN)/(FNN-1.0))                             019240
      SMZ2=SQRT((SMZ2-SMZ*SMZ*FNN)/(FNN-1.0))                             019260
      RETURN                                                              019280
      END                                                                 019300
```

APPENDIX B

PROGRAM WBRL

```
      PROGRAM WBRL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7)
      COMMON X(150,9),Y(150,9),Z(150,9),XX(150,9),YY(150,9),ZZ(150,9)
     1,TITLE(8),T(150),VRES(150),ARES(150),XA(150),YA(150),
     2 ZA(150),FMN(12),FMX(12)
      DIMENSION DATA(1024),FMNC(3,2),FMXC(3,2),IS(9),IE(9)
      DATA END/5H99999/,NP/11/,CON/1.0E10/,FCT/0.7/,FCTC/0.85/,INC/4/
     1, TCON/1.0E-05/,NMAX/150/
      CALL PLOTS(DATA,1024,7)
      CALL PLOT(0.0,-0.5,-3)
      CALL PLOT(0.0,0.7,-3)
      CALL FACTOR(FCT)
      CALL DATE(TODAY)
      CALL TIME(CLOCK)
      NS=(NP-1)/2
   10 READ(5,1000) TEST,TCOMP,DT
      IF (EOF(5)) 999,20
   20 READ(5,1100) TITLE
      IF (DT .LT. TCON) DT=0.002
      NST=0
      DO 25 I=1,NMAX
      T(I)=FLOAT(I-1)*DT
      IF (ABS(TCOMP-T(I)) .LT. TCON) NST=I
   25 CONTINUE
      IF (NST .LT. 1) WRITE(6,3300)
      IERR=0
      DO 90 K=1,5
      J2=2*K
      J1=J2-1
      IF (K .EQ. 5) J2=J1
      I=1
      READ(5,1200) TOM,(X(I,J),Y(I,J),Z(I,J),J=J1,J2)
      DO 30 I=1,NMAX
      IF (ABS(T(I)-TOM) .LT. TCON) GO TO 35
   30 CONTINUE
      IDK=(J1+1)/2
      IF (IERR .EQ. 0) WRITE(6,3050)
      WRITE(6,3010) TEST,IDK,TOM
      IERR=1
      GO TO 60
   35 IS(J1)=I
      IS(J2)=I
      IF (I .EQ. 1) GO TO 50
      DO 40 J=J1,J2
      X(I,J)=X(1,J)
      Y(I,J)=Y(1,J)
   40 Z(I,J)=Z(1,J)
   50 I=I+1
      IF (I .GT. NMAX) GO TO 55
      READ(5,1200) TOM,(X(I,J),Y(I,J),Z(I,J),J=J1,J2)
      IF (TOM .GT. 930.0) GO TO 70
      IF (ABS(TOM-T(I)) .LT. TCON) GO TO 50
      IF (IERR .EQ. 0) WRITE(6,3050)
      IERR=IERR+1
      IDK=(J1+1)/2
      WRITE(6,3000) TEST,IDK,T(I),TOM
```

```
      GO TO 60
   55 IF (IERR .EQ. 0) WRITE(6,3050)
      IOK=(J1+1)/2
      WRITE(6,3060) NMAX,IOK
   60 READ(5,1300) CK
      IF (CK .EQ. END) GO TO 70
      GO TO 60
   70 IE(J1)=I-1
      IE(J2)=I-1
   80 CONTINUE
      IF (IERR) 100,100,10
  100 MAXT=MAX0(IE(1),IE(3),IE(5),IE(7),IE(9))-NS
      DO 200 J=1,9
      N=IE(J)-IS(J)+1
      N1=IS(J)+NS
      N2=IE(J)-NS
      N3=N1+NS
      N4=N2-NS
      N5=N3+NS
      N6=N4-NS
      DO 160 I=1,12
      FMN(I)=CON
  160 FMX(I)=-CON
      I=IS(J)
      CALL SM(T,X(I,J),XX(I,J),N,NP)
      CALL SM(T,Y(I,J),YY(I,J),N,NP)
      CALL SM(T,Z(I,J),ZZ(I,J),N,NP)
C  COMPUTE VELOCITY COMPONENTS:
      CALL DERIV1(T,XX(I,J),X(I,J),N,NP,1)
      CALL DERIV1(T,YY(I,J),Y(I,J),N,NP,1)
      CALL DERIV1(T,ZZ(I,J),Z(I,J),N,NP,1)
      DO 170 II=N3,N4
      X(II,J)=X(II,J)/12.0
      Y(II,J)=Y(II,J)/12.0
  170 Z(II,J)=Z(II,J)/12.0
C  COMPUTE ACCELERATION COMPONENTS:
      CALL DERIV1(T,X(I,J),XA(I),N,NP,2)
      CALL DERIV1(T,Y(I,J),YA(I),N,NP,2)
      CALL DERIV1(T,Z(I,J),ZA(I),N,NP,2)
      LINE=60
      DO 190 I=N1,N2
      IF (LINE-50) 175,172,172
  172 WRITE(6,2500) TODAY,CLOCK,TEST,TITLE,NP
      WRITE(6,2505) J
      WRITE(6,2510)
      LINE=0
  175 FMN(1)=AMIN1(FMN(1),XX(I,J))
      FMN(2)=AMIN1(FMN(2),YY(I,J))
      FMN(3)=AMIN1(FMN(3),ZZ(I,J))
      FMX(1)=AMAX1(FMX(1),XX(I,J))
      FMX(2)=AMAX1(FMX(2),YY(I,J))
      FMX(3)=AMAX1(FMX(3),ZZ(I,J))
      IF (I .LT. N3 .OR. I .GT. N4) GO TO 178
C  COMPUTE RESULTANT LINEAR VELOCITY:
      VRES(I)=SQRT(X(I,J)**2+Y(I,J)**2+Z(I,J)**2)
```

```
      FMN(5)=AMIN1(FMN(5),X(I,J))
      FMN(6)=AMIN1(FMN(6),Y(I,J))
      FMN(7)=AMIN1(FMN(7),Z(I,J))
      FMN(8)=AMIN1(FMN(8),VRES(I))
      FMX(5)=AMAX1(FMX(5),X(I,J))
      FMX(6)=AMAX1(FMX(6),Y(I,J))
      FMX(7)=AMAX1(FMX(7),Z(I,J))
      FMX(8)=AMAX1(FMX(8),VRES(I))
      IF (I .LT. N5 .OR. I .GT. N6) GO TO 180
C   COMPUTE RESULTANT LINEAR ACCELERATION:
      ARES(I)=SQRT(XA(I)**2+YA(I)**2+ZA(I)**2)
      FMN(9)=AMIN1(FMN(9),XA(I))
      FMN(10)=AMIN1(FMN(10),YA(I))
      FMN(11)=AMIN1(FMN(11),ZA(I))
      FMN(12)=AMIN1(FMN(12),ARES(I))
      FMX(9)=AMAX1(FMX(9),XA(I))
      FMX(10)=AMAX1(FMX(10),YA(I))
      FMX(11)=AMAX1(FMX(11),ZA(I))
      FMX(12)=AMAX1(FMX(12),ARES(I))
      GO TO 185
  178 WRITE(6,2600) I,T(I),XX(I,J),YY(I,J),ZZ(I,J)
      GO TO 187
  180 WRITE(6,2600) I,T(I),XX(I,J),YY(I,J),ZZ(I,J),X(I,J),Y(I,J)
     1,Z(I,J),VRES(I)
      GO TO 187
  185 WRITE(6,2600) I,T(I),XX(I,J),YY(I,J),ZZ(I,J),X(I,J),
     1 Y(I,J),Z(I,J),VRES(I),XA(I),YA(I),ZA(I),ARES(I)
  187 LINE=LINE+1
  190 CONTINUE
      WRITE(6,2700) (FMN(I),I=1,3),(FMN(I),I=5,12)
      WRITE(6,2750) (FMX(I),I=1,3),(FMX(I),I=5,12)
      CALL PLT(J,N1,N2,N3,N4,N5,N6,MAXT,TEST)
      IF (J .LT. 7 .OR. J .GT. 8) GO TO 200
      JJ=J-6
      FMNC(1,JJ)=FMN(1)
      FMXC(1,JJ)=FMX(1)
      FMNC(2,JJ)=FMN(2)
      FMXC(2,JJ)=FMX(2)
      FMNC(3,JJ)=FMN(3)
      FMXC(3,JJ)=FMX(3)
  200 CONTINUE
      N2=MIN0(IE(7),IE(8))-NS
      CALL FACTOR(FCTC)
      N1=MAX0(IS(7),IS(8))+NS
      IF (N1 .GT. NST) NST=N1
      CALL PC(FMNC,FMXC,NST,N2,INC,TEST)
      CALL FACTOR(FCT)
      GO TO 10
  999 CALL PLOTE(NA)
      WRITE(6,3200) NA
      STOP "END OF JOB"
 1000 FORMAT(A10,2F10.0)
 1100 FORMAT(8A10)
 1200 FORMAT(F5.0,6F6.0)
 1300 FORMAT(A5)
```

```
 2500 FORMAT(1H1,*DATE: *,A10,12X,*TIME: *,A10,12X,*TEST NUMBER: *,
     1 A10// 1X,8A10,5X,I2,* POINT QUADRATIC FIT*)
 2505 FORMAT(/* DATA FOR VARIABLE CODE NUMBER *,I2)
 2510 FORMAT(/* FRAME  TIME*, 5X,*DISPLACEMENT (INCHES)*,14X,*VELOCITY (
     1FEET/SEC)*,16X,*ACCELERATION (FEET/SEC SQ)*/
     2*  NO.    (SEC)     X*,8X,*Y*,8X,*Z*,4X,2(5X,*X*,9X,*Y*,
     39X,*Z*,5X,*RESULTANT*))
 2600 FORMAT(1X,I4,F7.3,3F9.3,8F10.3)
 2700 FORMAT(* MINIMUM *,3X,3F9.3,8F10.3)
 2750 FORMAT(* MAXIMUM *,3X,3F9.3,8F10.3)
 3000 FORMAT(//* TEST: *,A10,5X,*TIME ERROR IN DECK*,I3,* --- T(I)= *,
     1 F7.3,* AND INCORRECT TIME = *,F7.3//* READ THROUGH REMAINING DECK
     2S IN THIS TEST AND PROCEED TO THE NEXT TEST.*)
 3010 FORMAT(//* TEST: *,A10,2X,*TIME ERROR IN DECK*,I3,* ---FIRST TIME=
     1*,F7.3/* FIRST TIME DOESN*T MATCH TIME DATA COMPUTED FROM GIVEN DT
     2.* / * SKIP THIS TEST.*)
 3050 FORMAT(1H1)
 3060 FORMAT(//* INDEX OF INPUT DATA POINTS IS GREATER THAN OR EQUAL TO
     1*,I3,* FOR DECK*,I3/* SOME DATA POINTS MAY HAVE BEEN LOST.*/
     2* INDEX OF THE FIRST DATA POINT = 1+T/DT, WHERE T IS THE TIME OF T
     3HE FIRST DATA POINT.*)
 3200 FORMAT(*1  END OF JOB: NUMBER OF BLOCK ADDRESSES= *,I3)
 3300 FORMAT(*1TIME OF FIRST POINT IN COMPOSITE PLOT (TCOMP) DOESN*T MAT
     1CH ANY STANDARD TIME COMPUTED FROM THE GIVEN DT.*//
     2 * COMPOSITE PLOT WILL CONTAIN ALL AVAILABLE POINTS.*)
      END
```

```
      SUBROUTINE SM(X,Y,YC,N,NP)
C   NP MUST BE AN ODD INTEGER .GE. 3.
C   COMPUTE THE COEFFICIENTS FOR A QUADRATIC LEAST SQUARES FIT OF 'NP'
C   POINTS AND COMPUTE THE FIT OF THE DATA (NO DERIVATIVES) 'YC(I)'.
      DIMENSION C(3),X(1),Y(1),YC(1)
      M=(NP-1)/2
      NN=N-M
      N1=NN+1
      DO 10 I=1,M
   10 YC(I)=0.0
      DO 20 I=N1,N
   20 YC(I)=0.0
      MM=M+1
      DO 100 I=MM,NN
      N1=I-M
      N2=I+M
      CALL QLSQ(X,Y,N1,N2,C)
      YC(I)=C(1)*X(I)*X(I)+C(2)*X(I)+C(3)
C     YP(I)=2.0*C(1)*X(I)+C(2)
C     YPP(I)=2.0*C(1)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DERIV1(X,Y,YP,N,NP,ID)
C     NP MUST BE AN ODD INTEGER .GE. 3.
C     ID=1 FOR FIRST DERIVATIVE.
C     ID=2 FOR SECOND DERIVATIVE.
C     COMPUTE THE COEFFICIENTS FOR A QUADRATIC LEAST SQUARES FIT OF 'NP'
C     POINTS AND COMPUTE THE FIRST DERIVATIVE 'YP(I)'.
      DIMENSION C(3),X(1),Y(1),YP(1)
      M=(NP-1)/2
      K=M+M*ID
      NN=N-K
      N1=NN+1
      DO 10 I=1,K
   10 YP(I)=0.0
      DO 20 I=N1,N
   20 YP(I)=0.0
      MM=K+1
      DO 100 I=MM,NN
      N1=I-M
      N2=I+M
      CALL QLSQ(X,Y,N1,N2,C)
      YP(I)=2.0*C(1)*X(I)+C(2)
C     YC(I)=C(1)*X(I)*X(I)+C(2)*X(I)+C(3)
C     YPP(I)=2.0*C(1)
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE QLSQ(X,Y,N1,N2,C)
      DIMENSION X(1),Y(1),C(1)
C
C   THIS SUBROUTINE COMPUTES THE QUADRATIC LEAST SQUARE COEFFICIENTS
C   'C(3)' FOR NP DATA POINTS (NP MUST BE AN ODD INTEGER  .GE. 3).
C   THE DATA NEED NOT BE EQUALLY SPACED.
C      C(1)*(X**2)+C(2)*X+C(3)=Y
C      C(1)*X+C(2)=Y
C   SUBSTITUTE XP=X-FF,  WHERE FF IS X((N1+N2)/2)
C   THEN C(3)=C(3)+C(1)*FF*FF-C(2)*FF
C          C(2)=C(2)-2.0*C(1)*FF
C          C(1)=C(1)
C
      F(A1,A2,A3,B1,B2,B3,C1,C2,C3)=A1*(B2*C3-B3*C2)+A2*(B3*C1-B1*C3)+A3
     1*(B1*C2-B2*C1)
      FN=FLOAT(N2-N1+1)
      NN=(N1+N2)/2
      FF=X(NN)
      Z1=0
      Z2=0
      Z3=0
      Z4=0
      Z5=0
      Z6=0
      Z7=0
   10 DO 20 I=N1,N2
      X2=X(I)-FF
      X1=X2*X2
      Z1=Z1+X2
      Z2=Z2+X1
      Z3=Z3+X1*X2
      Z4=Z4+X1*X1
      Z5=Z5+Y(I)
      Z6=Z6+X2*Y(I)
      Z7=Z7+X1*Y(I)
   20 CONTINUE
      DEN=F(Z4,Z3,Z2,Z3,Z2,Z1,Z2,Z1,FN)
      C(1)=F(Z7,Z6,Z5,Z3,Z2,Z1,Z2,Z1,FN)/DEN
      C(2)=F(Z4,Z3,Z2,Z7,Z6,Z5,Z2,Z1,FN)/DEN
      C(3)=F(Z4,Z3,Z2,Z3,Z2,Z1,Z7,Z6,Z5)/DEN
      C(3)=C(3)+C(1)*FF*FF-C(2)*FF
      C(2)=C(2)-2.0*C(1)*FF
      RETURN
      END
```

```
      [illegible]ROUTINE PLT(J,N1,N2,N3,N4,NF,N6,MAXT,TEST)
      COMMON X(150,8),Y(150,8),Z(150,8),XX(150,8),YY(150,8),ZZ(150,8)
     1,TITLE(8),T(150),VRES(150),ARES(150),XA(150),YA(150),
     2 ZA(150),FMN(12),FMX(12)
      DIMENSION TT(150)
      DATA DT/0.04/,DY/3.0/,SY/4.0/,DV/5.0/,DA/300./
      ST=FLOAT(IFIX(T(MAXT)/DT)+1)
      IF (ST .GT. 10.0 .OR. ST .LT. 3.0) WRITE(6,2000) ST
 2000 FORMAT(//' PROBABLE ERROR IN LENGTH OF TIME AXIS: ST=',F5.1)
      NP=N2-N1+1
      NF=N1-1
      DO 10 I=1,NP
   10 TT(I)=T(I+NF)
      TT(NP+1)=0.0
      TT(NP+2)=DT
      FPN=FMN(1)
      FMN(1)=FLOAT(IFIX(FMN(1)))
      IF (FPN .LT. 0.0) FMN(1)=FMN(1)-1.0
      FPN=FMN(2)
      FMN(2)=FLOAT(IFIX(FMN(2)))
      IF (FPN .LT. 0.0) FMN(2)=FMN(2)-1.0
      FPN=FMN(3)
      FMN(3)=FLOAT(IFIX(FMN(3)))
      IF (FPN .LT. 0.0) FMN(3)=FMN(3)-1.0
      CALL AXIS(0.0,0.0,10HTIME (SEC),-10,ST,0.0,0.0,DT)
      CALL AXIS(0.0,0.0,11HX DISP (IN),11,SY,90.0,FMN(1),DY)
      CALL AXIS(-0.75,0.0,11HY DISP (IN),11,SY,90.0,FMN(2),DY)
      CALL AXIS(-1.5,0.0,11HZ DISP (IN),11,SY,90.0,FMN(3),DY)
      CALL SYMBOL(-1.5,6.0,0.14,6HTEST: ,90.0,6)
      CALL SYMBOL(-1.5,6.84,0.14,TEST,90.0,10)
      CALL SYMBOL(-1.0,6.0,0.14,15HVARIABLE CODE: ,90.0,15)
      FPN=J
      CALL NUMBER(-1.0,8.1,0.14,FPN,90.0,-1)
      CALL PL(TT,XX(N1,J),NP,4,FMN(1),DY,SY)
      CALL PL(TT,YY(N1,J),NP,9,FMN(2),DY,SY)
      CALL PL(TT,ZZ(N1,J),NP,8,FMN(3),DY,SY)
      CALL PLOT(0.0,5.0,-3)
      CALL AXIS(0.0,0.0,10HTIME (SEC),-10,ST,0.0,0.0,DT)
      FPN=AMIN1(FMN(5),FMN(6),FMN(7),FMN(8))
      VMN=FLOAT(IFIX(FPN))
      IF (FPN .LT. 0.0) VMN=VMN-1.0
      CALL AXIS(0.0,0.0,17HVELOCITY (FT/SEC),17,SY,90.0,VMN,DV)
      NP=N4-N3+1
      NF=N3-1
      DO 50 I=1,NP
   50 TT(I)=T(I+NF)
      TT(NP+1)=0.0
      TT(NP+2)=DT
      CALL PL(TT,X(N3,J),NP,4,VMN,DV,SY)
      CALL PL(TT,Y(N3,J),NP,9,VMN,DV,SY)
      CALL PL(TT,Z(N3,J),NP,8,VMN,DV,SY)
      CALL PL(TT,VRES(N3),NP,7,VMN,DV,SY)
      CALL PLOT(0.0,5.0,-3)
      CALL AXIS(0.0,0.0,10HTIME (SEC),-10,ST,0.0,0.0,DT)
      FPN=AMIN1(FMN(9),FMN(10),FMN(11),FMN(12))
```

```
      AMN=FLOAT(IFIX(FPN/100.0))*100.0
      IF (FPN .LT. 0.0) AMN=AMN-100.0
      CALL AXIS(0.0,0.0,18HACCEL (FT/SEC/SEC),18,SY,90.0,[illegible])
      NP=N6-N5+1
      NF=N5-1
      DO 100 I=1,NP
  100 TT(I)=T(I+NF)
      TT(NP+1)=0.0
      TT(NP+2)=DT
      CALL PL(TT,XA(N5),NP,4,AMN,DA,SY)
      CALL PL(TT,YA(N5),NP,9,AMN,DA,SY)
      CALL PL(TT,ZA(N5),NP,8,AMN,DA,SY)
      CALL PL(TT,ARES(N5),NP,2,AMN,DA,SY)
      CALL PLOT(ST+5.0,-10.0,-3)
      RETURN
      END
```

```
      SUBROUTINE PL(T,Y,NP,NSYM,YMN,DY,SY)
      DIMENSION T(1),Y(1)
      DATA INT/20/
      N1=NP+1
      N2=NP+2
      Y(N1)=YMN
      Y(N2)=DY
      SS=SY
      IF (DY-100.) 10,20,20
   10 SS=SS+1.
      GO TO 30
   20 SS=SS+0.5
   30 YMX=YMN+SS*DY
      DO 60 I=1,NP
      IF (Y(I) .GT. YMX) Y(I)=YMX
   60 CONTINUE
      CALL LINE(T,Y,NP,1,INT,NSYM)
C     WRITE(6,2000) T(1),Y(1),T(NP),Y(NP),T(N1),T(N2),YMN,DY,SY,YMX,
C    1 SS,NP,NSYM
C2000 FORMAT(1X,11F9.3,I5,I3)
      RETURN
      END
```

```
      SUBROUTINE PC(FMNC,FMXC,NST,N2,INC,TEST)
      COMMON X(150,9),Y(150,9),Z(150,9),XX(150,9),YY(150,9),ZZ(150,9)
      DIMENSION FMNC(3,2),FMXC(3,2)
      DATA SX/5.0/,SZ/5.0/,DEL/2.0/,HT/0.105/,J1/7/,J2/8/,ISY7/2/,ISY8/3
     1/
      RDEL=1.0/DEL
      YMX=AMAX1(FMXC(2,1),FMXC(2,2))
      YMX=FLOAT(IFIX(YMX))
      IF (YMX .GE. 0.0) YMX=YMX+1.0
      YMN=AMIN1(FMNC(2,1),FMNC(2,2))
      SY=(YMX-YMN)*RDEL
      I=IFIX(SY)
      IF (SY .GT. FLOAT(I)) SY=FLOAT(I)+1.0
      IF (SY .GT. 12.0) GO TO 25
      GO TO 70
   25 SY=12.0
      YMX=YMN+SY*DEL
      IF (FMXC(2,1) .LE. YMX) GO TO 50
      DO 40 I=NST,N2,INC
      IF (YY(I,J1) .GT. YMX) YY(I,J1)=YMX
   40 CONTINUE
   50 IF (FMXC(2,2) .LE. YMX) GO TO 70
      DO 60 I=NST,N2,INC
      IF (YY(I,J2) .GT. YMX) YY(I,J2)=YMX
   60 CONTINUE
   70 XMN=AMIN1(FMNC(1,1),FMNC(1,2))
      ZMN=AMIN1(FMNC(3,1),FMNC(3,2))
      XMX=XMN+DEL*(SX+0.5)
      ZMX=ZMN+DEL*(SZ+0.5)
      IF (FMXC(1,1) .LE. XMX) GO TO 90
      DO 80 I=NST,N2,INC
      IF (XX(I,J1) .GT.XMX) XX(I,J1)=XMX
   80 CONTINUE
   90 IF (FMXC(1,2) .LE. XMX) GO TO 110
      DO 100 I=NST,N2,INC
      IF (XX(I,J2) .GT. XMX) XX(I,J2)=XMX
  100 CONTINUE
  110 IF (FMXC(3,1) .LE. ZMX) GO TO 130
      DO 120 I=NST,N2,INC
      IF (ZZ(I,J1) .GT. ZMX) ZZ(I,J1)=ZMX
  120 CONTINUE
  130 IF (FMXC(3,2) .LE. ZMX) GO TO 150
      DO 140 I=NST,N2,INC
      IF (ZZ(I,J2) .GT. ZMX) ZZ(I,J2)=ZMX
  140 CONTINUE
  150 CALL AXIS(0.0,0.0,11HY DISP (IN),-11,SY,0.0,YMN,DEL)
      CALL AXIS(0.0,0.0,11HZ DISP (IN),11,SZ,90.0,ZMN,DEL)
      DO 170 I=NST,N2,INC
      Y1=(YY(I,J1)-YMN)*RDEL
      Z1=(ZZ(I,J1)-ZMN)*RDEL
      CALL SYMBOL(Y1,Z1,HT,ISY7,0.0,-1)
      Y1=(YY(I,J2)-YMN)*RDEL
      Z1=(ZZ(I,J2)-ZMN)*RDEL
  170 CALL SYMBOL(Y1,Z1,HT,ISY8,0.0,-2)
      CALL PLOT(0.0,6.0,-3)
```

```
[illegible]
[illegible]
[illegible]
[illegible]
[illegible] *R EL
[illegible] ,HT,I [illegible]
 1= (Y(I,J2) YMN)*RCEL
 X1 (X(I,J2)-XMN)*RCEL
CALL SYMBOL(Y1,X1,HT,I [illegible]
CALL PLOT(SY+3.0,-6.0,-3)
CALL AXIS(0.0,0.0,11HX DISP [illegible]
CALL AXIS(0.0,0.0,11HZ DISP (IN),11,S2,90.0,ZMN, E [illegible]
DO 250 I=NS(,N2,INC
X1 (X(I,J1)-XMN)*RCEL
Z1=(Z(I,J1)-ZMN)*RCEL
CALL SYMBOL(X1,Z1,HT,IS [illegible],0.0,-1)
X1=(X(I,J2)-XMN)*RCEL
Z1=(Z(I,J2)-ZMN)*RCEL
CALL SYMBOL(X1,Z1,HT,IS [illegible],0.0,-2)
CALL SYMBOL(1.0,S2+3.9,HT,6HTEST [illegible],0.0,6)
X1=1.0+HT*6.0
CALL SYMBOL(X1, S2+3.9,HT,TEST,0.0,10)
CALL SYMBOL(1.0,S2+3.5,HT,ISY7,0.0,-1)
CALL SYMBOL(1.0,S2+3.2,HT,ISY8,0.0,-1)
CALL SYMBOL(1.15,S2+3.45,HT,15HVARIABLE CODE 7,0.0,15)
CALL SYMBOL(1.15,S2+3.15,HT,15HVARIABLE CODE 8,0.0,15)
CALL PLOT(SX+5.0,0.0,-3)
RETURN
END
```

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TECHNIQUES AND PROCEDURES APPLIED TO PHOTOMETRIC METHODS FOR TH--ETC(U)
OCT 80 P A GRAF, H T MOHLMAN F33615-76-C-0525
UNCLASSIFIED UDR-TR-79-115 AFAMRL-TR-80-61 NL

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APPENDIX C

PROGRAM RSD

```
      PROGRAM RSD(INPUT,OUTPUT,TAPE7,TAPE5=INPUT,TAPE6=OUTPUT)
C*********************************************************************
C
C  THIS RESTRAINT SYSTEM DYNAMICS (RSD) PROGRAM DRAWS 6 GRAPHS WHICH
C  SHOW THE MOTION OF THE HEAD, SHOULDER, ELBOW, WRIST, HIP, KNEE, AND
C  ANKLE AT 6 TIME POINTS DURING THE TEST.
C
C  THE INPUT VARIABLES READ BY SUBROUTINE INPT ARE DEFINED IN THE
C  WRITE-UP DESCRIBING THE INPUT DATA FORMAT.
C
C  THE COMMENTS IN THIS SOURCE LISTING SHOULD ADEQUATELY DOCUMENT THIS
C  SMALL PROGRAM.
C
C  THE FOLLOWING 5 SUBROUTINES ARE PART OF THIS PROGRAM:
C  FRAME -- DRAWS THE PLOT FRAME AND THE SEAT IN THE FRAME;
C  BODY  -- DRAWS BODY ELEMENTS;
C  TANG  -- COMPUTES AND DRAWS TANGENT LINES BETWEEN BODY ELEMENTS;
C  INPT -- READS ALL DATA EXCEPT THE TITLE CARD, COMPUTES CALIBRATION
C          FACTORS, AND CONVERTS DATA FROM COUNTS TO INCHES.
C  INTRPL- INTERPOLATES SHOULDER HARNESS POINTS BETWEEN THE FIRST AND
C          FIFTH BELT FIDICUAL.
C
C*********************************************************************
      DIMENSION DATA(1024),PX(6),PY(6),TITLE(6)
      COMMON X(18),Y(18),R(7),ANG,SX2,SY2,ITM
C  PX AND PY CONTAIN THE SIX PLOT ORIGINS IN SEQUENCE:
      DATA PX/0.0,3.25,3.25,-6.5,3.25,3.25/,PY/4.,0.,0.,-3.,0.,0./
      CALL PLOTS(DATA,1024,7)
C  PLOT DATA USING A 92 % SCALE FACTOR:
      FCTR=0.92
      CALL FACTOR(FCTR)
C  IP IS THE TIME OR PLOT INDEX; IP IS INCREMENTED FROM 1 TO 6 FOR THE 6
C  TIME SAMPLES:
   10 IP=0
C  READ AND PRINT THE PLOT TITLE:
      READ(5,1200) TITLE
      IF (EOF(5)) 999,20
   20 WRITE(6,2200) TITLE
      WRITE(6,2300)
C  SUBROUTINE INPT READS THE REMAINING SETUP DATA PLUS THE 0 TIME DATA
C  AND CONVERTS THE DATA FROM COUNTS TO INCHES:
      CALL INPT(IP)
C  CONVERT RADII TO PLOT SCALE INCHES;
C  THE PLOT SCALE IS 1/2 INCH = 1 FOOT (BEFORE APPLICATION OF SCALE
C  FACTOR 'FCTR' ABOVE):
      DO 30 I=1,7
   30 R(I)=R(I)/24.
      WRITE(6,2000) (R(I),I=1,7),ANG
      IP=IP+1
      II=18
      GO TO 55
   50 IP=IP+1
C  CALIB IS AN ENTRY POINT IN SUBROUTINE INPT; DATA ARE READ AND
C  CALIBRATED FOR THE IP-TH FRAME:
      CALL CALIB(IP)
```

```
      II=16
C  CONVERT ALL X AND Z-AXIS DATA  TO PLOT SCALE INCHES AND ADJUST TO
C  LOWER LEFT PLOT ORIGIN (X AND Z ARE PRESENTLY REFERENCED TO THE
C  INTERSECTION OF THE SEAT BACK AND SEAT PAN):
   55 DO 60 I=1,II
      X(I)=X(I)/24.0+2.0
   60 Y(I)=Y(I)/24.0+0.5
C  PRINT X AND Y DATA IN PLOT SCALE INCHES:
      WRITE(6,2100) (X(I),Y(I),I=1,II)
C  SET ORIGIN FOR PLOT 'IP':
      CALL PLOT(PX(IP),PY(IP),-3)
C  IO AND IA CONTROL ORDINATE AND ABSCISSA ANNOTATION (0-- ANNOTATION
C  IS OMITTED;  1-- ANNOTATION IS DRAWN):
      IO=0
      IF (IP .EQ. 1 .OR. IP .EQ. 4) IO=1
      IA=0
      IF (IP .GE. 4) IA=1
C  DRAW PLOT AND CHAIR OUTLINE:
      CALL FRAME(IO,IA)
C  DRAW FIGURE IN THE CHAIR:
      CALL BODY
      IF (IP .LT. 6) GO TO 50
C  PRINT PLOT TITLE BELOW THE SET OF SIX PLOTS:
      CALL SYMBOL(-5.95,-1.0,0.14,TITLE,0.0,60)
      CALL PLOT(5.0,0.0,-3)
      GO TO 10
  999 CALL PLOTE
      STOP 'END OF JOB'
 1200 FORMAT(6A10)
 2000 FORMAT(* RADII IN PLOT SCALE INCHES PLUS THE NOSE-TRAGEON ANGLE  I
     1N RADIANS ARE:*/(11X,8F10.3))
 2100 FORMAT(* CALIBRATED DATA POINTS IN PLOT SCALE INCHES ARE:*/
     1 (11X,8F10.3))
 2200 FORMAT(*1 TEST TITLE: *,6A10)
 2300 FORMAT(//* CALIBRATION DATA, RADII, AND CALIBRATED DATA ARE PRINTE
     1D IN THE FOLLOWING SEQUENCE FOR INDEX I=1 TO 16:*/
     2 5X,*HIP, KNEE, ANKLE, SHOULDER, */5X,*ELBOW, WRIST, TRAGEON, NOSE
     3,*/5X,*LAP HARNESS BUCKLE, AND 7 SHOULDER HARNESS POINTS.*//
     4* CHECK WRITE-UP OF INPUT CARD FORMATS FOR VARIABLE DEFINITIONS.*)
      END
```

```
      SUBROUTINE FRAME(IO,IA)
C
C  THIS SUBROUTINE DRAWS THE PLOT FRAME PLUS THE CHAIR WITHIN THE FRAME.
C  THE PLOT SCALE IS 1/2 INCH = 1 FOOT.
C
      COMMON X(18),Y(18),R(7),ANG,SX2,SY2,ITM
      DIMENSION IABSC(7),IORD(5)
      DATA IABSC/2H-4,2H-3,2H-2,2H-1,2H 0,2H 1,2H 2/,IORD/1H0,1H1,1H2,
     11H3,1H4/,HGHT/0.07/,SX/3.0/,SY/2.5/
C  DEFINE IMAGE FRAME:
      CALL PLOT(0.0,0.0,3)
      CALL PLOT(SX,0.0,2)
      CALL PLOT(SX,SY,2)
      CALL PLOT(0.,SY,2)
      CALL PLOT(0.,0.,2)
C  DRAW DASHED LINE AT DECK HEIGHT--2.94' ABOVE ABSCISSA:
      Y1=2.94/24.
      XD=0.096774
      X1=-XD
      DO 20 I=1,16
      X1=X1+XD
      CALL PLOT(X1,Y1,3)
      X1=X1+XD
   20 CALL PLOT(X1,Y1,2)
C  DRAW X-AXIS TIC MARKS:
      X1=0.
      Y1=0.07
      DO 40 I=1,5
      X1=X1+0.5
      CALL PLOT(X1,0.0,3)
   40 CALL PLOT(X1,Y1,2)
C  DRAW Y-AXIS TIC MARKS:
      X1=0.07
      Y1=0.
      DO 60 I=1,4
      Y1=Y1+0.5
      CALL PLOT(0.0,Y1,3)
   60 CALL PLOT(X1,Y1,2)
C  FOR IA>0, DRAW ABSCISSA ANNOTATION:
      IF (IA) 85,85,70
   70 X1=-1.5*HGHT
      Y1=-.12
      DO 80 I=1,7
      CALL SYMBOL(X1,Y1,HGHT,IABSC(I),0.0,2)
   80 X1=X1+0.5
C  FOR IO>0, DRAW ORDINATE ANNOTATION:
   85 IF (IO) 120,120,90
   90 X1=-1.5*HGHT
      Y1=-0.5*HGHT
      DO 100 I=1,5
      Y1=Y1+0.5
  100 CALL SYMBOL(X1,Y1,HGHT,IORD(I),0.0,1)
C  PRINT ELAPSED TIME IN UPPER LEFT CORNER:
  120 CALL SYMBOL (0.2,2.25,HGHT,ITM,0.0,3)
      CALL SYMBOL(0.48,2.25,HGHT,4HMSEC,0.0,4)
```

```
C  DRAW SEAT CONFIGURATION:
C  SX2,SY2 ARE THE COORDINATES OF THE UPPER LEFT CORNER OF THE CHAIR
C  SEAT PAN; THE SLOPE OF THE SEAT PAN IS 7.25 DEGREES AND THE SLOPE
C  OF THE SEAT BACK IS 12.67 DEGREES.
      SX2=1.261
      SY2=0.594
      CALL PLOT(1.261,0.5,3)
      CALL PLOT(SX2,SY2,2)
      CALL PLOT(2.0,0.5,2)
      CALL PLOT(2.38,2.19,2)
C  DRAW SEAT BACK HEAD REST:
      CALL PLOT(2.262,1.637,3)
      CALL PLOT(2.223,1.646,2)
      CALL PLOT(2.314,2.052,2)
      CALL PLOT(2.356,2.043,2)
      RETURN
      END
```

```
      SUBROUTINE BODY
C
C   THIS SUBROUTINE DRAWS THE BODY ELEMENTS PLUS THE SHOULDER HARNESS AND
C   LAP BELT POINTS IN EACH FRAME.
C
      DIMENSION U(9),V(9)
      COMMON X1,X2,X3,X4,X5,X6,X7,X8,BX(8),XS8,XL8,Y1,Y2,Y3,Y4,Y5,Y6,Y7,
     1Y8,BY(8),YS8,YL8,R1,R2,R3,R4,R5,R6,R7,ANG,SX2,SY2,ITM
      DATA A1/0.0/,A2/360.0/,HGHT/0.07/, IBCD/4/
C   DRAW HIP AND KNEE CIRCLES:
      CALL CIRCLE(X1+R1,Y1,A1,A2,R1,R1,A1)
      CALL CIRCLE(X2+R2,Y2,A1,A2,R2,R2,A1)
C   IPLT=1 FOR HIP-TO-KNEE TANGENT LINES AND IPLT>1 FOR ALL OTHER
C   CALLS TO SUBROUTINE 'TANG':
      IPLT=1
C   COMPUTE HIP-TO-KNEE TANGENT LINES:
      CALL TANG(X1,Y1,X2,Y2,R1,R2,IPLT,SX2,SY2)
   75 IPLT=2
C   DRAW ANKLE CIRCLE:
      CALL CIRCLE(X3+R3,Y3,A1,A2,R3,R3,A1)
C   DRAW ANKLE-TO-KNEE TANGENT LINES:
      CALL TANG(X2,Y2,X3,Y3,R2,R3,IPLT,SX2,SY2)
C   DRAW SHOULDER, ELBOW AND WRIST CIRCLES AND TANGENTS:
      CALL CIRCLE(X4+R4,Y4,A1,A2,R4,R4,A1)
      CALL CIRCLE(X5+R5,Y5,A1,A2,R5,R5,A1)
      CALL CIRCLE(X6+R6,Y6,A1,A2,R6,R6,A1)
      IPLT=3
      CALL TANG(X4,Y4,X5,Y5,R4,R5,IPLT,SX2,SY2)
      IPLT=4
      CALL TANG(X5,Y5,X6,Y6,R5,R6,IPLT,SX2,SY2)
C   DRAW HEAD CIRCLE:
      CALL CIRCLE(X7+R7,Y7,A1,A2,R7,R7,A1)
C   PLOT EYE POINT:
      CALL SYMBOL(X8,Y8,HGHT/2.0,3,0.0,-1)
C   COMPUTE AND DRAW HEAD Z-AXIS LINE:
C   THETA -- ANGLE TRAGEON-NOSE LINE MAKES IN X,Y AXIS THROUGH TRAGEON
C            POINT.
      THETA=ATAN2(Y8-Y7,X8-X7)
      IF (THETA .LT. 0.0) THETA=THETA+6.2831853
C   ANG -- ANGLE BETWEEN TRAGEON-NOSE LINE AND HEAD Z-AXIS.
C   ANG IS COMPUTED IN RADIANS IN SUBROUTINE INPT:
      THETA=THETA-ANG
      XP=R7*COS(THETA)
      YP=R7*SIN(THETA)
      XL1=X7+XP
      XL2=X7-XP
      YL1=Y7+YP
      YL2=Y7-YP
C   PLOT Z-AXIS LINE DETERMINED BY POINTS XL1,YL1 AND XL2,YL2:
      CALL PLOT(XL1,YL1,3)
      CALL PLOT(XL2,YL2,2)
      WRITE(6,2100) XL1,YL1,XL2,YL2
C   PLOT RESTRAINT BELT LOWER ATTACH POINT (XL8,YL8) PLUS THE LAP BUCKLE
C   POINT (BX(1),BY(1)):
      CALL SYMBOL(XL8,YL8,HGHT,IBCD,0.0,-1)
```

```
      CALL PLOT(BX(1),BY(1),2)
C  INTERPOLATE 9 POINTS BETWEEN 1-ST AND 5-TH BELT POINTS; INTERPOLATE
C  X DATA FOR A GIVEN Y:
      DY=(BY(5)-BY(1))/10.
      DO 100 I=1,9
  100 U(I)=BY(1)+DY*FLOAT(I)
      I1=6
      I2=9
      CALL INTRPL(I1,BY(1),BX(1),I2,U,V)
      WRITE(6,2000) BX(1),BY(1),(V(I),U(I),I=1,9),(BX(I),BY(I),I=5,8)
C  PLOT THE 9 INTERPOLATED POINTS:
      DO 120 I=1,9
  120 CALL PLOT(V(I),U(I),2)
C  PLOT THE LAST 4 SHOULDER HARNESS POINTS:
      DO 130 I=5,8
  130 CALL PLOT(BX(I),BY(I),2)
C  PLOT THE SHOULDER HARNESS SEAT ATTACH POINT:
      CALL SYMBOL(XSB,YSB,HGHT,IBCD,0.0,-2)
      RETURN
 2000 FORMAT(* LAP BELT AND SHOULDER HARNESS X,Y POINTS ARE (BUCKLE POIN
     1T, 9 INTERPOLATED POINTS, PLUS THE LAST 4 SHOULDER HARNESS POINTS)
     2:*/ (11X,8F10.3))
 2100 FORMAT(* X,Y POINTS AT BOTH ENDS OF THE HEAD Z-AXIS LINE ARE:*/
     1  11X,4F10.3)
      END
```

```
      SUBROUTINE TANG(X1,Y1,X2,Y2,R1,R2,IPLT,SX2,SY2)
      DIMENSION LABEL(2,4)
      DATA D90/1.57079633/
     1,LABEL/10H   HIP AND,8H KNEE   ,10H  KNEE AND,8H ANKLE  ,
     2 10HSHOULDER A,8HND ELBOW,10H ELBOW AND,8H WRIST  /
C  THIS SUBROUTINE COMPUTES AND DRAWS THE TANGENT LINES CONNECTING
C  THE TWO CIRCLES.  THE CIRCLE CENTERS ARE AT X1,Y1 AND X2,Y2 AND THE
C  RADII ARE R1 AND R2.  THE CIRCLES WITH TANGENT LINES FORM THE BODY
C  SEGMENTS.
C  WHEN THIS ROUTINE WAS CODED, R1 WAS ALWAYS > R2 AND X1,Y1 WAS
C  ALWAYS FURTHER FROM THE PLOT ORIGIN THAN X2,Y2; THUS WE WERE ALWAYS
C  WORKING FROM THE SMALL CIRCLE TO THE LARGE CIRCLE.  HOWEVER, THE
C  ALGORITHMS WERE DEREVED SUCH THAT THE COMPUTATIONS SHOULD BE CORRECT
C  EVEN IF THESE CONDITIONS ARE NOT FULLFILLED.
      XD=X1-X2
      YD=Y1-Y2
C  SLOPE -- SLOPE OF LINE THROUGH THE TWO CIRCLE CENTER POINTS:
      SLOPE=YD/XD
      THETA=ATAN(ABS(SLOPE))
      FCT=SIGN(1.0,SLOPE)
C  DIST -- DISTANCE BETWEEN THE TWO CIRCLE CENTER POINTS:
      DIST=SQRT(XD*XD+YD*YD)
      PHI=ASIN((R1-R2)/DIST)
C  ANGLES THETA AND PHI ARE REQUIRED TO COMPUTE ANGLES A1 AND A2 WHICH
C  ARE THEN USED TO DEFINE THE X AND Y COORDINATES OF THE TANGENT
C  POINTS:
      A1=D90-THETA-FCT*PHI
      A2=D90-THETA+FCT*PHI
      SU=SIN(A1)
      SL=SIN(A2)
      CU=-FCT*COS(A1)
      CL=FCT*COS(A2)
C  COMPUTE X AND Y UPPER AND LOWER TANGENT POINTS FOR CIRCLE 1:
      XU1=X1+R1*CU
      YU1=Y1+R1*SU
      XL1=X1+R1*CL
      YL1=Y1-R1*SL
C  COMPUTE X AND Y UPPER AND LOWER TANGENT POINTS FOR CIRCLE 2:
      XU2=X2+R2*CU
      YU2=Y2+R2*SU
      XL2=X2+R2*CL
      YL2=Y2-R2*SL
C  PLOT UPPER TANGENT LINE:
      CALL PLOT(XU1,YU1,3)
      CALL PLOT(XU2,YU2,2)
      WRITE(6,2100) LABEL(1,IPLT),LABEL(2,IPLT),XU1,YU1,XL1,YL1,XU2,YU2,
     1 XL2,YL2
C  PLOT LOWER TANGENT LINE:
   50 CALL PLOT(XL1,YL1,3)
      IF (IPLT-1) 100,100,60
   60 CALL PLOT(XL2,YL2,2)
      RETURN
C  BOTTOM HIP-TO-KNEE TANGENT LINE MAY INTERFERE WITH THE UPPER LEFT
C  CORNER OF THE SEAT PAN (SX2,SY2); CHECK AND DRAW LINE ACCORDINGLY.
C  IF IT DOES INTERFERE, COMPUTE THE TANGENT FROM THE CORNER OF THE
```

```
C   SEAT PAN TO THE KNEE CIRCLE.
C   COMPUTE SLOPE OF TANGENT LINE:
  130 SLOPE=(YL1-YL2)/(XL1-XL2)
C   COMPUTE Y (YC) COORDINATE FOR SEAT PAN SX2 POINT; IF YC > SY2, THEN
C   THE SEAT PAN DOESN'T INTERFERE WITH THE HIP-TO-KNEE TANGENT LINE:
      YC=SLOPE*(SX2-XL2)+YL2
      IF (YC .GE. SY2) GO TO 60
C   COMPUTE TANGENT FROM SX2,SY2 --> KNEE CIRCLE (R2):
C   KNEE CIRCLE CENTER MUST BE TO THE LEFT OF SX2,SY2:
      IF (X2 .GE. SX2) GO TO 150
C   DIST -- DISTANCE FROM CORNER OF THE SEAT PAN TO THE CENTER OF THE
C   KNEE CIRCLE:
      DIST=SQRT((SX2-X2)**2+(SY2-Y2)**2)
      IF (DIST .GT. R2) GO TO 120
C OMIT TANGENT LINE FOR DIST < R2----SEAT PAN POINT IS WITHIN THE
C   RADIUS OF THE KNEE CIRCLE:
      WRITE(6,2300) DIST,R2
      GO TO 150
C   ALP IS THE SLOPE OF THE LINE FROM THE CENTER OF THE KNEE CIRCLE TO
C   THE SEAT PAN POINT:
  120 ALP=ATAN((SY2-Y2)/(SX2-X2))
C   COMPUTE GAMMA USING THE TWO KNOWN SIDES OF THE TRIANGLE:
      GAM=ACOS(R2/DIST)
C   COMPUTE 'PHI' --- ANGLE IN NEW TRIANGLE REQUIRED TO COMPUTE TANGENT
C   POINT XL2,YL2 BELOW:
      PHI=GAM-ALP
C   COMPUTE X AND Y COORDINATES OF TANGENT POINT ON THE KNEE CIRCLE:
      XL2=X2+R2*COS(PHI)
      YL2=Y2-R2*SIN(PHI)
C   DRAW THE TANGENT LINES FROM THE HIP CIRCLE TO THE CORNER OF THE SEAT
C   PAN TO THE KNEE CIRCLE:
      CALL PLOT(SX2,SY2,2)
      WRITE(6,2400) SLOPE,YC,SY2,DIST,ALP,GAM,XL2,YL2
      GO TO 60
  150 CALL PLOT(SX2,SY2,2)
 2100 FORMAT(' UPPER AND LOWER TANGENT POINTS FOR THE ',A10,A8,' CIRCLE
     1ARE:'/(11X,8F10.3))
 2300 FORMAT(' THE DISTANCE FROM THE CORNER OF THE SEAT PAN TO THE CENTE
     1R OF THE KNEE CIRCLE =',F8.3,'  THE KNEE RADIUS =',F8.3)
 2400 FORMAT(' SLOPE, YC, SY2, DIST, ALP, GAM, XL2, YL2 FROM THE CORNER
     1 OF THE SEAT PAN TO KNEE CIRCLE TANGENT POINT COMPUTATIONS:'/
     2 11X,8F10.3)
      RETURN
      END
```

```
      SUBROUTINE INPT(IP)
      DIMENSION BAF(10),X1(7),Y1(7),X2(7),Y2(7),CAL(16)
      COMMON X(16),XSB,XLB,Y(16),YSB,YLB,R(7),ANG,SX2,SY2,ITM
C  THIS SUBROUTINE READS ALL INPUT DATA EXCEPT THE 'TITLE' CARD,
C  COMPUTES ALL CONVERSION FACTORS (COUNTS TO INCHES), AND
C  CALIBRATES ALL DATA.
C  THE DATA POINT SEQUENCE IS:
C      INDEX          PARAMETER
C        1            HIP
C        2            KNEE
C        3            ANKLE
C        4            SHOULDER
C        5            ELBOW
C        6            WRIST
C        7            TRAGEON
C        8            NOSE
C        9            HARNESS BUCKLE
C      10-16          SHOULDER HARNESS
      DATA RAD/57.2957795/
C  READ AND WRITE ALL TEST PARAMETER INPUT DATA;
C  ALL PARAMETER SYMBOLS SHOULD BE DEFINED IN THE WRITE-UP DESCRIBING
C  THE FORMAT OF THE INPUT DATA:
      READ(5,1000) DPS,DSC,DPF,DSF,XSB,YSB,XLB,YLB,XASSF,YASSF
      WRITE(6,3010) DPS,DSC,DPF,DSF,XSB,YSB,XLB,YLB,XASSF,YASSF
      READ(5,1000) BAF
      WRITE(6,3020) BAF
      READ(5,1000) XPF,YPF,XPA,YPA,XSF,YSF,XSA,YSA
      WRITE(6,3030) XPF,YPF,XPA,YPA,XSF,YSF,XSA,YSA
      READ(5,1100) (X1(I),Y1(I),X2(I),Y2(I),I=2,6)
      WRITE(6,3040) (X1(I),Y1(I),X2(I),Y2(I),I=2,6)
      READ(5,1000) TX,TY,EX,EY
      WRITE(6,3050) TX,TY,EX,EY
C  COMPUTE PANEL AND SEAT CONVERSION FACTORS:
      PCAL=SQRT((XPF-XPA)**2+(YPF-YPA)**2)/DPF
      SCAL=SQRT((XSF-XSA)**2+(YSF-YSA)**2)/DSF
C  COMPUTE DISTANCE FROM THE FOCAL POINT TO THE SEAT (SS):
      SS=(DPS*DSF)/(DPF-(SCAL/PCAL)*DPF)
      WRITE(6,3060) PCAL,SCAL,SS
C  COMPUTE THE ANGLE THE TRAGEON - NOSE LINE MAKES WITH THE Z-AXIS
C  THROUGH THE HEAD:
      DX=TX-EX
      DY=TY-EY
      ANG=ATAN(ABS(DX/DY))
C  COMPUTE REMAINING CONVERSION FACTORS:
      DO 100 I=1,10
  100 CAL(I)=SS*SCAL/(SS+DSC-BAF(I)/2.0)
      DO 110 I=13,16
  110 CAL(I)=CAL(10)
      DCAL=CAL(13)-CAL(9)
C  COMPUTE RADII OF ALL BODY ELEMENTS EXCEPT THE HEAD AND THE HIP:
      DO 150 I=2,6
  150 R(I)=SQRT((X2(I)-X1(I))**2+(Y2(I)-Y1(I))**2)/(2.0*CAL(I))
      ENTRY CALIB
C  READ PHOTO DATA FOR EACH TIME SET:
      READ(5,1200)  ITM
```

```
      WRITE(6,2100) ITM
      READ(5,1100)  XSFF,YSFF,XSAF,YSAF,(X(I),Y(I),I=1,16)
      WRITE(6,3100) XSFF,YSFF,XSAF,YSAF,(X(I),Y(I),I=1,16)
C  COMPUTE CALIB FACTORS FOR 3 SHOULDER STRAP POINTS WITHOUT FIDUCIALS:
      YBU=Y(9)
      YFCT=DCAL/(Y(13)-YBU)
      CAL(10)=CAL(9)+YFCT*(Y(10)-YBU)
      CAL(11)=CAL(9)+YFCT*(Y(11)-YBU)
      CAL(12)=CAL(9)+YFCT*(Y(12)-YBU)
      WRITE(6,2200) CAL
C  CALIBRATE ALL DATA FOR I-TH FRAME:
      XSAF=XSAF/SCAL
      YSAF=YSAF/SCAL
      XF=XASSF-XSAF
      YF=YASSF-YSAF
      DO 200 I=1,16
      X(I)=X(I)/CAL(I)+XF
  200 Y(I)=Y(I)/CAL(I)+YF
      IF (IP .GT. 0) RETURN
C  COMPUTE RADII OF HIP AND HEAD (FOR 0 FRAME ONLY):
      XHR=0.23076923*Y(7)-1.0190769
      R(7)=(XHR-X(7))*COS(12.6667/RAD)
      YSP=-0.12634*X(1)
      R(1)=(Y(1)-YSP)*COS(7.25/RAD)
      RETURN
 1000 FORMAT(5X,10F7.0)
 1100 FORMAT(5X,8F7.0)
 1200 FORMAT(5X,A3)
 2100 FORMAT(*1ITM=*,A3,* MSEC;  INPUT DATA FOR THIS TIME FRAME ARE:*/)
 2200 FORMAT(* CALIBRATION DATA FOR THIS TIME FRAME ARE:*/
     1 (11X,8F10.3))
 3010 FORMAT(*0DPS  ETC.=*,10F10.3)
 3020 FORMAT(* BAF  ETC.=*,10F10.3)
 3030 FORMAT(* XPF  ETC.=*,10F10.3)
 3040 FORMAT(* X1   ETC.=*,8F10.3/(11X,8F10.3))
 3050 FORMAT(* TX   ETC.=*,4F10.3)
 3060 FORMAT(* PCAL ETC.=*,3F10.3)
 3100 FORMAT(*0XSFF ETC.=*,8F10.3/(11X,8F10.3))
      END
```

```
      SUBROUTINE INTRPL(L,X,Y,N,U,V)
C INTERPOLATION OF A SINGLE-VALUED FUNCTION
C TAKEN FROM COMMUNICATIONS OF ACM, OCTOBER 1972, VOL 15, NUMBER 12.
C  ALGORITHM NUMBER 433.
C  REPRINT PRIVILEGE GRANTED BY PERMISSION OF THE ASSOCIATION FOR
C  COMPUTING MACHINERY.
C
C THIS SUBROUTINE INTERPOLATES, FROM VALUES OF THE FUNCTION
C GIVEN AS ORDINATES OF INPUT DATA POINTS IN AN X-Y PLANE
C AND FOR A GIVEN SET OF X VALUES (ABSCISSAS), THE VALUES OF
C A SINGLE-VALUED FUNCTION Y=Y(X).
C
C
C THE INPUT PARAMETERS ARE
C
C     L = NUMBER OF INPUT DATA POINTS(MUST BE 2 OR GREATER)
C     X = ARRAY OF DIMENSION L STORING THE X VALUES(ABSCISSAS) OF INPUT
C         DATA POINTS (IN ASCENDING ORDER)
C     Y = ARRAY OF DIMENSION L STORING THE Y VALUES(ORDINATES) OF INPUT
C         DATA POINTS
C     N = NUMBER OF POINTS AT WHICH INTERPOLATION OF THE Y VALUE
C         (ORDINATE) IS DESIRED (MUST BE 1 OR GREATER)
C     U = ARRAY OF DIMENSION N STORING THE X VALUES (ABSCISSAS) OF
C         DESIRED POINTS
C
C THE OUTPUT PARAMETER IS
C
C     V = ARRAY OF DIMENSION N WHERE THE INTERPOLATED Y VALUES
C         (ORDINATES) ARE TO BE DISPLAYED
C
C DECLARATION STATEMENTS
C
      DIMENSION X(L),Y(L),U(N),V(N)
      EQUIVALENCE (P0,X3),(Q0,Y3),(Q1,T3)
      REAL  M1,M2,M3,M4,M5
      EQUIVALENCE (UK,DX),(IMN,X2,A1,M1),(IMX,X5,A5,M5),
     1 (J,SW,SA),(Y2,W2,W4,Q2),(Y5,W3,Q3)
C
C PRELIMINARY PROCESSING
C
   10 L0=L
      LM1=L0-1
      LM2=LM1-1
      LP1=L0+1
      N0=N
      IF(LM2 .LT. 0)  GO TO 90
      IF (N0 .LE. 0)  GO TO 91
      DO 11 I=2,L0
      IF (X(I-1)-X(I)) 11,95,96
   11 CONTINUE
      IPV=0
C
C MAIN DO-LOOP
C
      DO 80 K=1,N0
```

```
      UK=U(K)
C
C ROUTINE TO LOCATE THE DESIRED POINT
C
   20 IF(LM2 .EQ. 0)  GO TO 27
      IF (UK .GE. X(L0))  GO TO 26
      IF(UK .LT. X(1))  GO TO 25
      IMN=2
      IMX=L0
   21 I=(IMN+IMX)/2
      IF (UK .GE. X(I))  GO TO 23
   22 IMX=I
      GO TO 24
   23 IMN=I+1
   24 IF (IMX .GT. IMN)  GO TO 21
      I=IMX
      GO TO 30
   25 I=1
      GO TO 30
   26 I=LP1
      GO TO 30
   27 I=2
C
C CHECK IF I=IPV
C
   30 IF (I .EQ. IPV)  GO TO 70
      IPV=I
C
C ROUTINES TO PICK UP NECESSARY X AND Y VALUES AND
C          TO ESTIMATE THEM IF NECESSARY
C
   40 J=I
      IF (J .EQ. 1)  J=2
      IF (J .EQ. LP1)   J=L0
      X3=X(J-1)
      Y3=Y(J-1)
      X4=X(J)
       Y4=Y(J)
      A3=X4-X3
      M3=(Y4-Y3)/A3
      IF (LM2 .EQ. 0)  GO TO 43
      IF (J .EQ. 2)   GO TO 41
      X2=X(J-2)
      Y2=Y(J-2)
      A2=X3-X2
      M2=(Y3-Y2)/A2
      IF (J .EQ. L0)   GO TO 42
   41 X5=X(J+1)
      Y5=Y(J+1)
      A4=X5-X4
      M4=(Y5-Y4)/A4
      IF (J .EQ. 2)   M2=M3+M3-M4
      GO TO 45
   42 M4=M3+M3-M2
      GO TO 45
```

```
   43 M2=M3
      M4=M3
   45 IF (J .LE. 3)  GO TO 46
       A1=X2-X(J-3)
      M1=(Y2-Y(J-3))/A1
      GO TO 47
   46 M1=M2+M2-M3
   47 IF (J .GE. LM1)  GO TO 48
      A5=X(J+2)-X5
      M5=(Y(J+2)-Y5)/A5
      GO TO 50
   48 M5=M4+M4-M3
C
C NUMERICAL DIFFERENTIATION
C
   50 IF (I .EQ. LP1)   GO TO 52
      W2=ABS(M4-M3)
      W3=ABS(M2-M1)
      SW=W2+W3
      IF (SW .NE. 0.0)   GO TO 51
      W2=0.5
      W3=0.5
      SW=1.0
   51 T3=(W2*M2+W3*M3)/SW
      IF (I .EQ. 1)   GO TO 54
   52 W3=ABS(M5-M4)
      W4=ABS(M3-M2)
      SW=W3+W4
      IF (SW .NE. 0.0)  GO TO 53
      W3=0.5
      W4=0.5
      SW=1.0
   53 T4=(W3*M3+W4*M4)/SW
      IF (I .NE. LP1)   GO TO 60
      T3=T4
      SA=A2+A3
      T4=0.5*(M4+M5-A2*(A2-A3)*(M2-M3)/(SA*SA))
      X3=X4
      Y3=Y4
      A3=A2
      M3=M4
      GO TO 60
   54 T4=T3
       SA=A3+A4
      T3=0.5*(M1+M2-A4*(A3-A4)*(M3-M4)/(SA*SA))
      X3=X3-A4
      Y3=Y3-M2*A4
      A3=A4
      M3=M2
C
C DETERMINATION OF THE COEFFICIENTS
C
   60 Q2=(2.0*(M3-T3)+M3-T4)/A3
      Q3=(-M3-M3+T3+T4)/(A3*A3)
C
```

```
C COMPUTATION OF THE POLYNOMIAL
C
   70 DX=UK-P0
   80 V(K)=Q0+DX*(Q1+DX*(Q2+DX*Q3))
      RETURN
C
C ERROR EXIT
C
   90 WRITE (6,2090)
      GO TO 99
   91 WRITE (6,2091)
      GO TO 99
   95 WRITE (6,2095)
      GO TO 97
   96 WRITE (6,2096)
   97 WRITE (6,2097)  I,X(I)
   99 WRITE (6,2099)  L0,N0
      RETURN
C
C FORMAT STATEMENTS
C
 2090 FORMAT (1X/22H  ***    L = 1 OR LESS./)
 2091 FORMAT (1X/22H  ***    N = 0 OR LESS./)
 2095 FORMAT (1X/27H  ***    IDENTICAL X VALUES./)
 2096 FORMAT(1X/33H  ***   X VALUES OUT OF SEQUENCE./)
 2097 FORMAT (6H   I =,I7,10X,6HX(I) =,E12.3)
 2099 FORMAT (6H   L =,I7,10X,3HN =,I7/36H ERROR DETECTED IN ROUTINE
     1INTRPL)
      END
```

APPENDIX D

PROGRAM CHIFPD

```
      PROGRAM CHIFPO(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C***********************************************************************
C
C  PROGRAM 'CHIFPO' CALIBRATES THE 'HIFPO' PROGRAM INPUT DATA.
C
C  THE PROGRAM COMPUTES THE FOLLOWING FOR EACH (X,Z) DATA POINT:
C     (1) MAGNITUDE R=SQRT(X**2+Z**2) ---> R IN COUNTS
C     (2) ANGLE ALPHA=R/(138.6848159*57.29577951) ---> ALPHA IN RADIANS
C     (3) ADJUSTED R=RA=R/COS(ALPHA) ---> RA IN COUNTS
C     (4) ADJUSTED X=XA=X*RA/R ---> XA IN COUNTS
C     (5) ADJUSTED Z=ZA=Z*RA/R ---> ZA IN COUNTS
C
C  DATA ARE READ AND PRINTED IN THE STANDARD 'HIFPO' PROGRAM FORMAT.
C
C***********************************************************************
      DIMENSION X(4),Z(4),XA(4),ZA(4)
      DATA RAD/57.29577951/,CON/138.6848159/
      FCT=CON*RAD
   10 READ(5,1000) F1,(X(I),Z(I),I=1,4)
      IF (EOF(5)) 999,20
   20 DO 100 I=1,4
      R=SQRT(X(I)**2+Z(I)**2)
      ALPH=R/FCT
      C1=COS(ALPH)
      XA(I)=X(I)/C1
      ZA(I)=Z(I)/C1
  100 CONTINUE
      WRITE(6,1000) F1,(XA(I),ZA(I),I=1,4)
      GO TO 10
  999 STOP
 1000 FORMAT(A5,8F7.0)
      END
```


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